AD-A105 162 CONSTRUCTION ENGINEERING RESEARCH LAB (ARMY) CHAMPAIGN IL F/G 13/1
COMPARISON OF BUILDING LOADS ANALYSIS AND SYSTEM THERMODYNAMICS--ETC(U)
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TECHNICAL REPORT E-174
August 1981
(BLAST Validation)

COMPARISON OF BUILDING LOADS ANALYSIS AND SYSTEM THERMODYNAMICS (BLAST) COMPUTER PROGRAM SIMULATIONS AND MEASURED ENERGY USE FOR ARMY BUILDINGS

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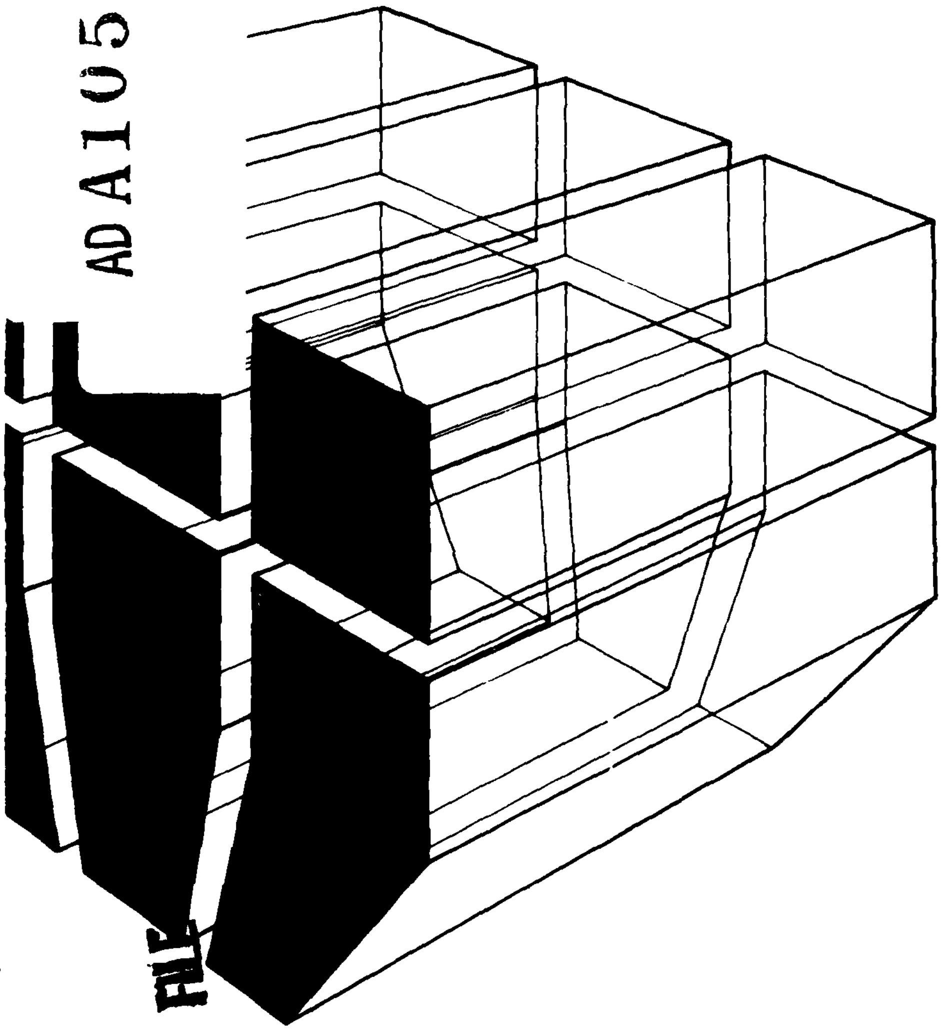

by
Dale Herron

CERL

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
14 CERL-TR-E-174

2. GOVT ACCESSION NO.
AD-A105162

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
6 COMPARISON OF BUILDING LOADS ANALYSIS AND SYSTEM THERMODYNAMICS (BLAST) COMPUTER PROGRAM SIMULATIONS AND MEASURED ENERGY USE FOR ARMY BUILDINGS

5. TYPE OF REPORT & PERIOD COVERED
9 FINAL rept.

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
10 Dale Herron

8. CONTRACT OR GRANT NUMBER(s)
17 G

9. PERFORMING ORGANIZATION NAME AND ADDRESS
U. S. ARMY
CONSTRUCTION ENGINEERING RESEARCH LABORATORY
P.O. Box 4005, Champaign, IL 61820

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
16 4A762731AT41-G-001

11. CONTROLLING OFFICE NAME AND ADDRESS
11

12. REPORT DATE
Aug[redacted]981

13. NUMBER OF PAGES
52 12 54

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report)
Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Copies are obtainable from the National Technical Information Service
Springfield, VA 22151

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

BLAST (computer program)
buildings
energy consumption

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report describes the results of study which compared actual energy-use data collected for two typical Army buildings by the Army's Fixed Facilities Energy Monitoring Project with energy-use data predicted by the U.S. Army Construction Engineering Research Laboratory's (CERL's) Building Loads Analysis and System Thermodynamics (BLAST) energy analysis computer program.

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It was concluded that to compare actual building energy use with energy use predicted by BLAST, accurate, concurrent hourly measurements of weather data, energy-use data, occupancy-dependent parameters, and equipment operating parameters must be obtained. However, within the data collection restraints of this study, BLAST predicted building boundary energy consumption (including both electrical and gas consumption) to within 10 to 12 percent for two typical Army buildings. BLAST also accurately predicted electrical consumption of a chiller package for the same Army buildings.

It was also concluded that BLAST can be used to evaluate energy conservative design alternatives, since most of the hard-to-define effects of building occupants on building energy use are constant and therefore relatively unimportant. But when BLAST is used to predict actual energy performance, values for building geometry, materials, schedules, controls, and heating, cooling, and ventilating systems must be precise and the effects of occupants on building energy use must be carefully described.

FOREWORD

This work was performed for the Directorate of Military Programs, Office of the Chief of Engineers (OCE), under Project 4A762731AT41,"Design, Construction, and Operation and Technology for Military Facilities"; Technical Area G, "Military Energy Technology"; Work Unit 001, "BLAST Validation." Mr. Ed Zulkofske, DAEN-MPE-E, was the Technical Monitor.

This work was performed by the Energy Systems (ES) Division of the U.S. Army Construction Engineering Research Laboratory (CERL). Mr. R. G. Donaghy is Chief of ES. Much work that contributed to this effort was performed under contract DACA 80-78-R-0004. Appreciation for their support during data collection is expressed to Yandell and Hiller, Inc., Fort Worth, TX.

COL Louis J. Circeo is Commander and Director of CERL, and Dr. L. R. Shaffer is Technical Director.

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SYSTEM THERMODYNAMICS (BLAST) COMPUTER PROGRAM
SIMULATIONS AND MEASURED ENERGY USE FOR ARMY BUILDINGS

1 INTRODUCTION

Background

The Building Loads Analysis and System Thermodynamics (BLAST) computer program predicts hourly space heating and cooling requirements, simulates hourly fan system performance, and simulates hourly performance of conventional heating and cooling, solar energy, or total energy systems for new and existing buildings.[1] The program has been field tested and was released for general use in December 1977. The BLAST program is considerably more powerful, accurate, and provides more information to the designer than hand calculation methods. Consequently, it is now widely used by the Army, Department of Defense, other Federal agencies, and private architect/engineers in the United States, Europe, and Canada to determine both expected energy use in new and existing buildings, and to help optimize building and energy system design.

Although extensive BLAST field tests have proved the program to be accurate and usable, a study comparing BLAST simulation results to measured field data was considered desirable. Such a study could identify weaknesses in the BLAST program and help define important building parameter inputs. Therefore, the U.S. Army Construction Engineering Research Laboratory (CERL) was asked to analyze and compare actual measured data against BLAST-predicted energy consumption for two Army buildings in an attempt to verify the prediction capabilities of the BLAST program.

Objective

The objective of this report is to compare the results of BLAST simulations with measured building energy consumption data.

Approach

The following approach was used to perform this comparative study:

1. Two Army buildings were selected from among some 100 Army buildings participating in an energy monitoring project designed to measure actual, onsite energy-use and climate data.

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[1] D. C. Hittle, The Building Loads Analysis and System Thermodynamics (BLAST) Program, Version 2.0, Users Manual, Vols I and II, Technical Report (TR) E-153/ADA072272 and ADA0722730; and E. Sowell, The Building Loads Analysis and System Thermodynamics (BLAST) Program Input Booklet, TR E-154/ADA072435 (U.S. Army Construction Engineering Research Laboratory [CERL], June 1979).

2. Detailed data concerning the buildings' design and operation, including construction drawings, heating, ventilating, and air-conditioning (HVAC) system information, occupancy use profiles, lighting and equipment usage, etc., were obtained by onsite visits, surveys, and measurement.

3. A BLAST input deck was created for each building.

4. Hourly weather data and concurrent detailed building energy-use data were obtained from onsite instruments for a short time period (about 1 month).

5. BLAST simulations were performed using onsite weather data and comparisons were made between predicted energy use and actual energy use for the selected buildings.

6. Results were analyzed to determine the extent of agreement between the BLAST simulation and measured energy use and to determine the cause of any disagreements.

7. Building boundary energy-use data for the two buildings and weather data for the National Weather Service observation site closest to each building were obtained for a time period of several months.

8. BLAST simulations were performed for the longer time period. Comparisons were made between the predicted and actual energy use for each building.

Scope

The results of Steps 1 through 6 in the approach section above are described in CERL Interim Report E-161.[2] This report summarizes those results and describes the work performed in Steps 7 and 8.

Mode of Technology Transfer

The results of this work will be referenced in a future version of the Energy Conservative Design Guide.

[2] D. Herron, L. Windingland, and D. Hittle, Comparison of Building Loads Analysis and System Thermodynamics (BLAST) Computer Program Simulations and Measured Energy Use for Army Buildings, Interim Report (IR) E-161/ADA085573 (CERL, May 1980).

2 DISCUSSION

Energy Conservative Design Rationale

Energy efficiency is one of the major considerations in the design of new facilities. Prescriptive standards for new facility designs such as those given in the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) Standard 90-75 and the Department of Defense Criteria Manual 4270.1-M specify the types of materials, minimum insulation levels, amount and types of glass, type of HVAC systems, system operation and control schedules, etc. which may help ensure that a facility will be energy conservative in a certain climate. While these standards ensure a relatively energy efficient design, they severely restrict the design options available to architects and engineers.[3]

To circumvent this problem, the Department of the Army uses the design energy budget procedure, which assigns a maximum yearly design energy consumption rate, on a square foot basis, to each facility type (e.g., office, store) according to climatic zones.[4] The actual facility design must be shown to consume no more than the amount of energy specified in the design energy budget for that facility type and climatic region. This allows for much flexibility in the design, provided the target design energy budget can be met.

Design Energy Budgets

Design energy budgets are determined for various facility types from computer simulations using energy analysis programs such as BLAST and by analyzing actual energy-use data. Design energy budgets are determined by fixing the construction details of the buildings at the levels specified by the prescriptive standards as discussed above, and by fixing the building operating parameters (occupancy, thermostat settings, etc.) at typical levels. Compliance of an actual design is shown by computer simulation of the facility using the actual construction details and assuming the same set of typical building operating parameters.

While the design energy budget procedure ensures that the design of a facility is energy efficient, it cannot predict the actual energy consumption of a facility after it is built and in operation. This is because a facility's actual energy consumption is determined by many factors beyond the control of the designer. For example, the quality of the construction, the effects building occupants have on lighting levels, infiltration, thermostat settings, and the actual performance of the HVAC system and its controls can significantly impact energy consumption. Thus, the energy budget computed for a facility is only an indication of what a facility's energy consumption would be if it were constructed as designed, and operated according to the energy conservative operating rules used in the budget procedure. Generally, the

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[3] Energy Conservation in New Building Design, ASHRAE Standard 90-75 (American Society of Heating, Refrigeration, and Air Conditioning Engineers [ASHRAE], 1975); and DOD Construction Criteria Manual 4270.1-M (Department of Defense [DOD], Office of the Assistant Secretary of Defense, 1 October 1972).

[4] Interim Energy Budgets for New Facilities, Engineer Technical Letter (ETL) 1110-3-309 (Department of the Army, 30 August 1979).

energy budget procedure indicates the best energy performance that the facility could have; it is the target energy performance that building operators should try to achieve.

Energy Analysis Computer Programs

Energy analysis computer programs, such as BLAST, were developed to help designers create energy efficient buildings. These programs let designers evaluate design options for new and retrofit facilities by giving designers a way to rank design alternatives according to their relative energy savings. For these kinds of analyses, energy consumption factors beyond the designer's control, such as construction quality and occupant behavior, are not critical, since they do not affect how alternatives are ranked. Therefore, the energy efficient building operating rules used in these analyses can provide energy-use data that are useful for budget comparisons.

Such energy performance analyses indicate the optimum energy performance a facility could have for the climate used in the simulation. The facility's actual energy performance will agree with this prediction only if the actual weather conditions match those used in the simulation, and if the building is operated in the manner assumed in the simulation.

If, for validation purposes, the predictions from an energy analysis program such as BLAST are to be compared to the long-term, actual energy consumption data of a facility, precise data about the building's actual operation and energy use must be obtained by intensive monitoring and energy-use surveys. To do this, accurate data describing the building's occupancy level, lights and equipment use, thermostat settings, and mechanical system operation, as well as actual weather data for the desired period, must be available. Actual energy-use data on each of the facility's major components must also be collected, so energy-use comparisons can be made at the individual component level. Enough information about a building must be collected to ensure that when predicted and actual data are compared, the cause of any disagreement can be identified as an error in either the BLAST input deck for the building or the BLAST simulation algorithms.

Building Selection

From 1976 to 1978, the Fixed Facilities Energy Consumption Investigation (FFECI), an Army-sponsored energy monitoring project, measured hourly building boundary energy consumption data for more than 100 Army buildings at different installations throughout the continental United States. Hourly climatic data, including ambient temperature, dew point temperature, wind speed, wind direction, barometric pressure, and solar radiation were also collected using appropriate sensors, electronic interface devices, and recorder systems.[5]

[5] L. M. Windingland and B. J. Sliwinski, Fixed Facilities Energy Consumption Investigation -- Initial Energy Data, IR E-120/ADA051074 (CERL, January 1978); L. Windingland, B. Sliwinski, and A. Mech, Fixed Facilities Energy Consumption Investigation Data Users Manual, IR E-127/ADA052708 (CERL, February 1978); and B. Sliwinski, D. Leverenz, and L. Windingland, Fixed Facilities Energy Consumption Investigation -- Data Analysis, IR E-143/ADA066513 (CERL, February 1979).

However, only a few of these 100 buildings were monitored closely enough to allow their individual energy use, including heating and cooling requirements, to be identified. It was from among the buildings with measurable individual data that CERL selected two representative Army buildings for the BLAST prediction/comparison study.

The first building selected was a single-story, 18-chair dental clinic with laboratory at Fort Hood, TX. Figures 1 and 2 show the floor plan and typical wall, roof, and floor sections of the dental clinic, respectively. The clinic was built in 1968 and has a gross area of 9384 sq ft (872 m^2). It is constructed of block and brick and uses a steel truss roof system and built-up roof. It has an exterior wall area of 4050 sq ft (376 m^2), of which about 340 sq ft (32 m^2) are windows or glass doors. The clinic is served by a multizone air-handling system with 10 zones. A reciprocating chiller and air-cooled condenser package (60-ton capacity) supply the chilled water to the multizone system, and a gas-fired hot water boiler is used for heating. The clinic's hourly total electrical consumption, which includes the electrical consumption of the building's lights, dental equipment, HVAC equipment, chiller package, and the hourly total natural gas usage is being metered under the FFECI project.

The second building chosen was a battalion headquarters and classroom building built in 1974 at Fort Carson, CO. This one-story structure has a ground floor area of 18,907 sq ft (1757 m^2) and a basement area of 3330 sq ft (310 m^2). The building is 259 ft (79 m) long, 73 ft (24 m) wide, and has an exterior wall area of 8235 sq ft (765 m^2), of which 933 sq ft (87 m^2) are windows and glass doors. Figure 3 shows the building's floor plan. Figure 4 shows typical wall, roof, and floor sections. The building core is served by a seven-zone multizone air-handling system which receives its hot and chilled water from a remote central boiler/chiller plant. The wings at each end and the basement are served by single zone heating systems which also receive their hot water from the remote central plant. FFECI data being measured for this building include hourly total hot and chilled water energy supplied from the central plant and the hourly total electrical consumption, including building lights, office equipment, and HVAC equipment.

Construction Drawings

The as-built construction drawings for each of the buildings selected for analysis were obtained from each installation's Facilities Engineer and verified in the field. These drawings included floor plans, architectural details (including wall, roof, and floor construction details), electrical plans, mechanical plans, equipment lists and schedules, and HVAC control diagrams.

Building and HVAC System Data

A field survey and onsite measurements of system parameters were necessary to prepare accurate input for the BLAST program. A contractor, Yandell and Hiller, Inc., Fort Worth, TX, collected these additional field data for CERL; the contractor's data collection activities were divided into three tasks:

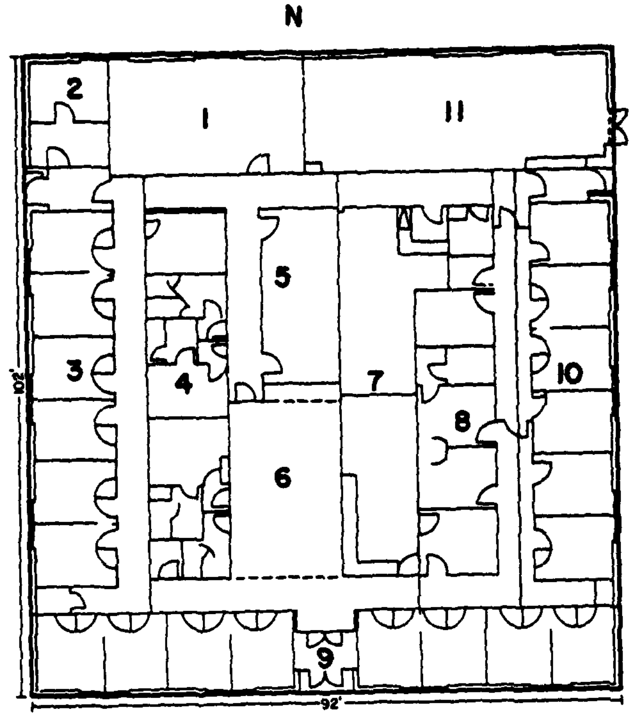

Figure 1. Dental clinic floor plan.

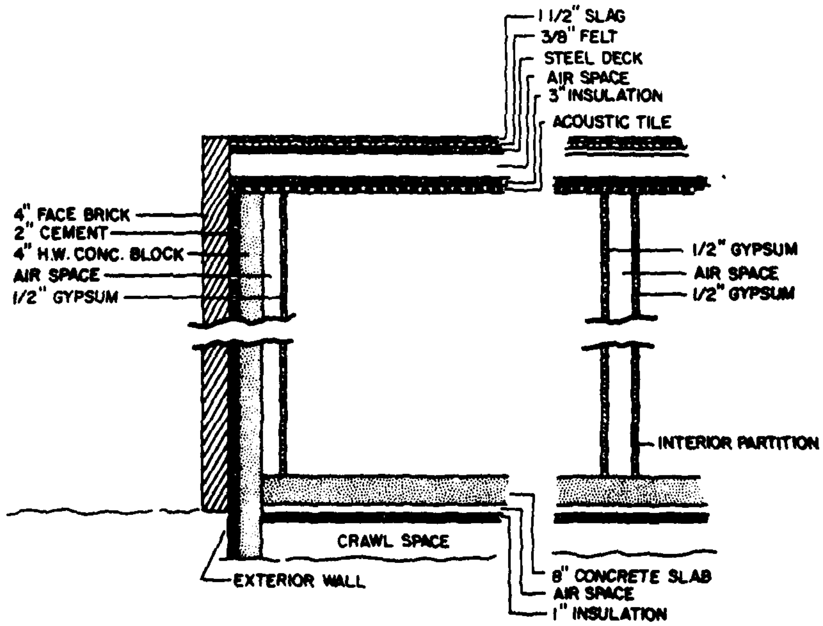

Figure 2. Dental clinic wall, floor, and ceiling details.

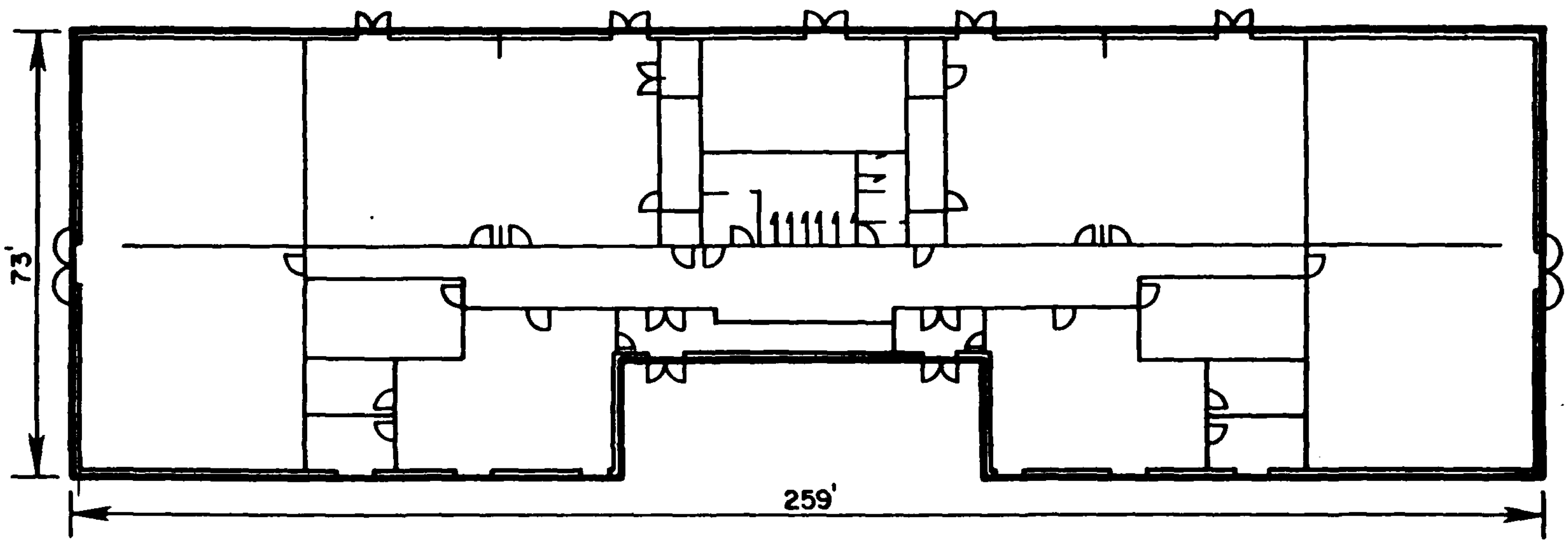

Figure 3. Battalion headquarters and classroom building floor plan.

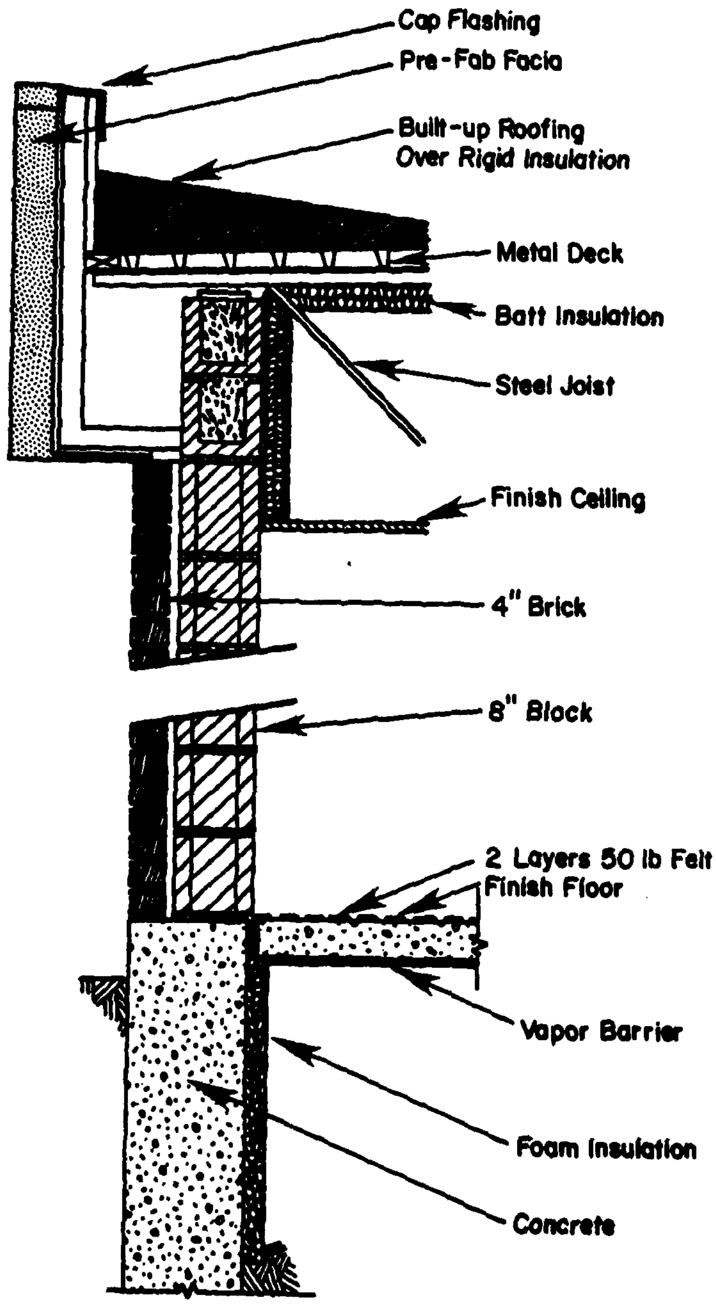

Figure 4. Battalion headquarters and classroom wall, floor, and ceiling details.

1. Task 1 -- Familiarization With Buildings. The contractor reviewed building drawings and made onsite visits to verify as-built drawings against the actual building. Particular emphasis was placed on building modifications; installed equipment capacities; verification of actual wall, roof, floor, and ceiling construction materials; equipment control strategies; and operating procedures.

2. Task 2 -- Building Survey. The contractor prepared and distributed an occupancy questionnaire which was analyzed to determine the building's occupancy profile (i.e., the number of occupants in the building, when they went to lunch, and when they left for the day). The contractor also observed the operation of the building, recording for short periods the number of times doors were opened, exhaust fan operation, and other parameters so an estimate could be made of the building's air infiltration. In addition, the contractor determined the capacities of installed mechanical equipment and obtained manufacturer's specifications or data sheets for each piece of equipment in the building, including air-handling unit fans, heating and cooling coils, boilers and chillers, unit heaters, water heaters, exhaust fans, and HVAC system controls.

3. Task 3 -- Data Monitoring. The contractor measured outside air quantities, return air quantities, total supply air flow, the supply air flow to each zone in the building, and air temperatures of both the hot and cold decks. In addition, each building's fan operating periods and full-load consumption were determined. Temporary electrical measuring devices were installed so the energy use of the heating and cooling systems' components could be separated from the remaining electrical energy used within the building. The contractor also installed temporary recording devices to monitor the detailed energy performance of one zone in each building. Building HVAC system controls were checked to determine the actual sequence of operation and, where possible, controller set point and throttling ranges. Table 1 lists the items surveyed, method of monitoring, and frequency and duration of monitoring.

The data listed in Table 1 were continuously recorded for the dental clinic at Fort Hood between 24 June and 26 July 1978. Data for the battalion headquarters and classroom building at Fort Carson were recorded between 4 August and 6 September 1978.

Computer Simulation for the Short Time Period

BLAST input decks were prepared to simulate both the dental clinic and the battalion headquarters and classroom building using data from field surveys, contractor measurements, and as-built drawings. Using actual onsite weather data, each building was simulated for the 1-month period when detailed energy use information was available. To ensure the independent integrity of the BLAST simulation, the FFECI energy-use data were not inspected before or during BLAST input preparation.

Table 1

BLAST Validation Data

Item Surveyed or Monitored	Collection Method	Number and Frequency of Sample	Duration Sample	Measuring Accuracy
Number of occupants	Questionnaire and survey	8 observations for both weekdays & weekend	2-4 days	±5%
Door & window openings	Physical survey	48 observations	2-4 days	±10%
Exhaust fan operation	Physical survey	24 observations	2-4 days	±10%
Zone				
Indoor temperature	Sensor	Continuous monitoring	2 each 2-week period	±1°F(±0.56°C)
Relative humidity	Sensor	Continuous monitoring	2 each 2-week period	±2%
Lighting & appliances	Sensor	Continuous monitoring	2 each 2-week period	±2%
Supply air temperature	Sensor	Continuous monitoring	2 each 2-week period	±2%
Supply volume	Rotating vane anemometer	12 measurements	2 different days each period	±2%
Building				
Mixed air dew-point temperature	Sensor	Continuous monitoring	2 each 2-week period	±1°F(±0.56°C)
Total fan supply volume	Pitot rack	Continuous monitoring	2 each 2-week period	±5%

Table 1 (Cont'd)

Item Surveyed or Monitored	Collection Method	Number and Frequency of Sample	Duration Sample	Measuring Accuracy
Return & outside air volume	Engineering calculations	Continuous monitoring	2 each 2-week period	$\pm 5\%$
Volume to each zone*	Pitot tube traverse	12 measurements	2 different days each period	$\pm 5\%$
Cold deck air temperature	Sensor	Continuous monitoring	2 each 2-week period	$\pm 1^{\circ}F (\pm 0.56^{\circ}C)$
Hot deck air temperature	Sensor	Continuous monitoring	2 each 2-week period	$\pm 1^{\circ}F (\pm 0.56^{\circ}C)$
Cold deck water temperature	Sensor	Continuous monitoring	2 each 2-week period	$\pm 0.5^{\circ}F (\pm 0.28^{\circ}C)$
Hot deck water temperature	Sensor	Continuous monitoring	2 each 2-week period	$\pm 0.5^{\circ}F (\pm 0.28^{\circ}C)$
Fan power	Sensor	Continuous monitoring	2 each 2-week period	$\pm 2\%$
Fan speed	Tachometer	1 observation	N/A	$\pm 2\%$
Mechanical equipment power	Sensor	Continuous monitoring	2 each 2-week period	$\pm 2\%$
Boiler "on-time"	Sensor	Continuous monitoring	2 each 2-week period	$\pm 2\%$
Water heater "on-time"	Sensor	Continuous monitoring	2 each 2-week period	$\pm 2\%$

*Volume is the volumetric airflow rate in cubic feet per minute.

Comparison of Actual and Simulated Results for the Short Time Period

After the BLAST simulations were completed, the actual energy-use data were inspected for the 1-month period for which the simulations were performed. Simulated and measured total consumption data were then compared for the total period and on an hourly basis to determine the agreement between BLAST-predicted and measured energy-use data. The hourly energy data for each building component were examined to ensure that cancelling errors did not result in unusually close agreement in total energy use for the simulation period. A statistical analyis was performed on the variances between the BLAST simulation and the actual energy use.

Computer Simulation for the Long Time Period

The BLAST simulations were repeated for each building for a period of several months using weather data obtained from the National Weather Service for the location closest to each building. For these periods, actual energy data included only the hourly building boundary energy consumption information available from the Army's energy monitoring project.

Comparison of Actual and Simulated Results for the Long Time Period

After the BLAST simulations were complete, data comparisons were made between the simulated and measured data.

3 ANALYSES AND FINDINGS -- DENTAL CLINIC

BLAST Input Deck

The dental clinic was divided into 10 simulation zones. Each simulation zone corresponded to a zone served by the clinic's multizone air-handling unit (Figure 1). Zone geometries and construction details of the walls, roof, and floor were determined from the construction drawings. The crawlspace was also simulated to accurately model heat transfer through the floor.

The internal electrical peak load and daily internal electrical load profile (which included building lights and dental equipment) was determined by analyzing contractor-supplied measured data (Figure 5). Peak electrical demand for each zone was estimated from a disaggregation of the peak internal building electrical demand, based on the distribution of lights and equipment within the building as determined by a building survey. The building's occupancy profile (Figure 6), zone peak occupancy (based on building-use patterns), and zone thermostat settings and control profiles were determined from contractor-supplied data.

Specific information about the HVAC system was obtained from control diagrams, control specifications, and measured or observed data. Design cooling coil parameters were obtained from the construction drawings. Design data for the water chiller package were obtained from manufacturers' catalogs for the specific unit installed in the building; the chiller part-load curve was determined from measured data (Figure 7). The peak electrical demands of the chiller, condenser, and HVAC fans were determined by contractor-supplied measured data. HVAC system air volume flow rates were also supplied by the contractor.

The BLAST input deck for the dental clinic is in Appendix A. Table 2 summarizes the fan system input parameters.

Computer Simulation -- Short Time Period

Actual weather data from Fort Hood, TX were available from the Army's energy monitoring project for the period 1 June through 6 July, 1978. Actual weather data were not available for the period 6 to 26 July 1978 because of an instrumentation malfunction.

A BLAST simulation was performed for the dental clinic for the period 1 June through 6 July. The simulation predicted the hourly total, internal building, fan, and chiller electrical consumption. Because the clinic's hot water supply pump was disabled during the simulation period, BLAST simulated the hot water boiler as being turned off; thus, no gas consumption was predicted.

Comparison of Data -- Short Time Period

For the period 1 June to 6 July 1978, hourly data on the building's total electrical consumption were available from the Army's energy monitoring

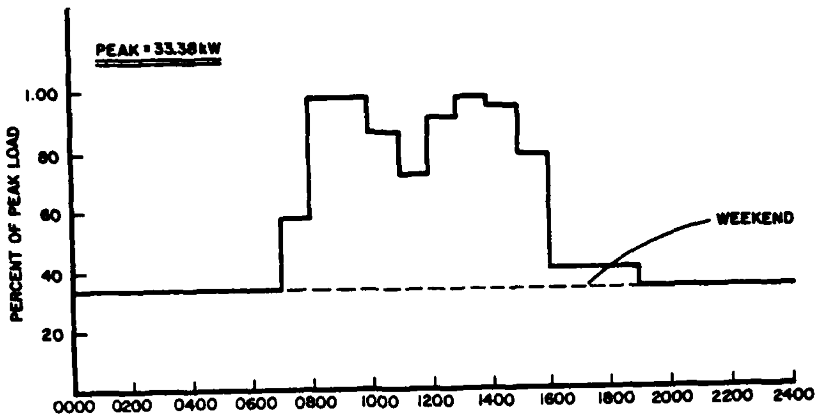

Figure 5. Dental clinic internal electric load profile (weekdays only).

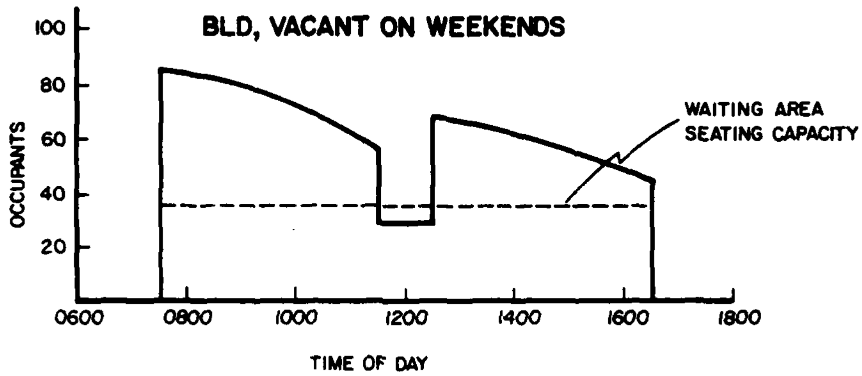

Figure 6. Dental clinic occupancy profile (weekdays only).

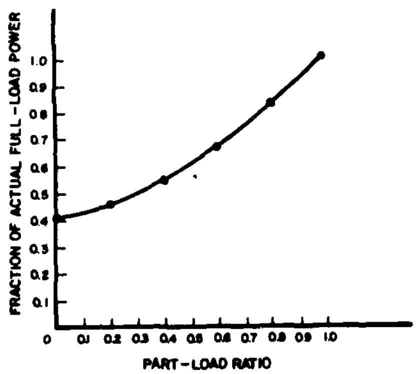

Figure 7. Dental clinic chiller package part-load power consumption.

Table 2

Fan System Parameters -- Dental Clinic

Type system = multizone
System operation = continuous

<u>Seasonal Component Schedules</u>

Heating coil on: 1 January; off: 31 December
Cooling coil on: 1 January; off: 31 December

Mixed air control = fixed amount
Fixed outside air volume = 1.942 m^3/s

Hot deck control = outside air control
Hot deck throttling range = 4.0°C
Hot deck control schedule = (48.89 at -12.11, 26.67 at 21.11)°C

Heating coil capacity = 1000 kW
Heating coil energy supply = hot water

Cold deck control = fixed set point
Cold deck throttling range = 2.77°C
Cold deck fixed temperature = 15.55°C

Zone Number	Zone Supply Air Volume (m^3/s)	Zone Exhaust Air Volume (m^3/s)
1	0.842	0.4719
2	0.1916	0.0
3	0.9486	0.0
4	0.3592	0.2832
5	0.2369	0.0
6	0.3931	0.0
7	0.4172	0.0
8	0.3912	0.0
9	1.060	0.0
10	0.9934	0.0

Total design supply air volume = 5.883 m^3/s

project; hourly (Table 3 and Figure 8) and total (Table 3) consumption comparisons between measured and predicted total electrical consumption were made. For the period 25 June to 1 July 1978, hourly electrical data for the building's internal and chiller electrical consumption were also available; hourly (Table 3 and Figure 9) and total (Table 3) comparisons were made between these measured and predicted data.

The comparison results in Table 3 show that BLAST-predicted total building electrical consumption is 12.1 percent higher than the measured total building electrical consumption. The correlation coefficient for the measured vs predicted data is 0.87. Figure 8 shows a plot of predicted and measured total electrical consumption for the week of 25 June to 1 July 1978.

To determine why measured and predicted total electrical consumption data disagreed, individual electrical load components were analyzed. Results for internal building and chiller package electrical consumption are shown in Table 3. A plot of predicted vs actual chiller electrical consumption data for the week of 25 June to 1 July 1978 is shown in Figure 9.

The results of the detailed analyses of the internal building electrical consumption prediction indicate that the profile predicts a consumption within 10 percent of the measured data and has a correlation coefficient of 0.90. The results also indicate that the internal building electrical consumption profile consistently overpredicts the electrical consumption.

The results of the detailed analyses of the chiller package electrical consumption prediction indicate agreement within 10 percent of the measured data; the correlation coefficient is 0.79. The chiller input predicts the low part-load operation almost exactly, but consistently overpredicts during the high part-load operating conditions of the chiller package (Figure 9).

Computer Simulation-- Long Time Period

While the short-term simulation was indicative of the accuracy of the dental clinic simulation model, comparison for a longer time period, including both the heating and cooling season, was desirable. Because the typical BLAST user does not have access to actual onsite weather for his or her simulation, it was decided to use weather data from the closest National Weather Service recording station -- Waco, TX. Continuous energy data were available from the Army's energy monitoring project for the period 15 March to 31 July 1980. Weather data were obtained for Waco, TX for that period, and using the dental clinic input deck (as described above) a BLAST simulation was performed. The simulation predicted the hourly total electrical consumption. It included the electrical consumption from building lights, dental equipment, HVAC equipment, the packaged chiller, and the hourly total gas consumption.

Table 3

Dental Clinic Comparison -- Short Time Period
Electrical Data Comparison

Total Building Electrical	Measured (kWh)	Predicted (kWh)	% Difference
1 June 0000 to 6 July 0900	44,687	50,091	-12.1
Internal Building Electrical			
25 June 0000 to 1800 and 26 June 0700 to 1 July 0900	2345	2581	-10.1
Chiller Electrical			
25 June 0000 to 1800 and 26 June 0200 to 1 July 0900	4597	5308	-9.6

Statistics (hourly)*	Total Bldg	Internal Bldg	Chiller
R**	0.87	0.90	0.79
DIFFAV (kW)	-5.87	-1.12	-1.25
DIFFVAR	55.90	39.20	6.26
DIFFSTD	7.43	4.36	6.26
PERAVE	-15.76	-46.03	-2.79
PERVAR	620.75	17,135.00	327.14
PERSTD	24.91	130.90	18.09
DABSAVE (kW)	7.30	3.44	4.97
DABSVAR	36.29	8.37	15.91
DABSSTD	6.02	2.89	3.99

* See Appendix C for definition of statistics
**Correlation coefficient

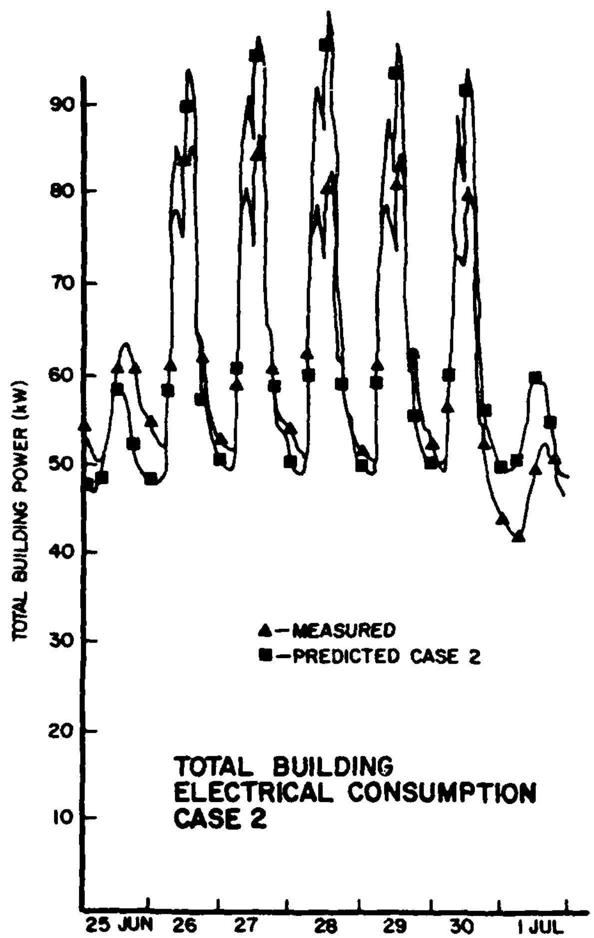

Figure 8. Dental clinic hourly total electrical consumption.

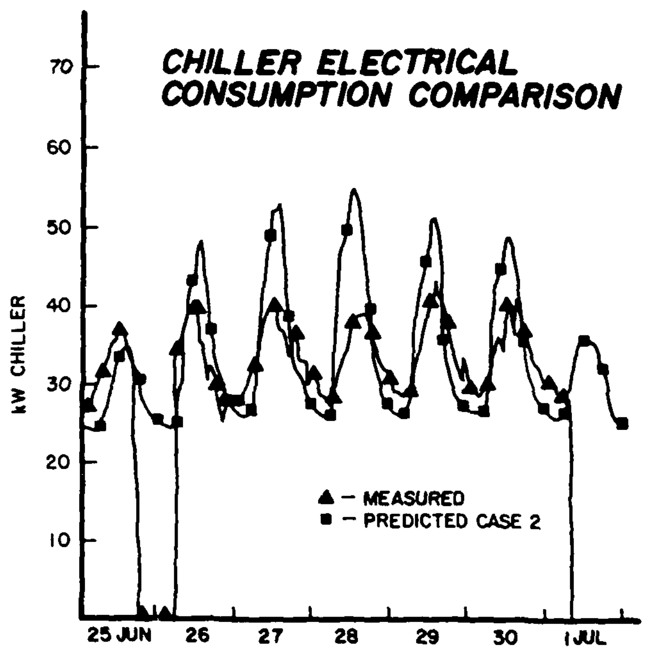

Figure 9. Dental clinic chiller electrical consumption.

Comparison of Data -- Long Time Period

After the simulation was completed, energy data from the Army's energy monitoring project were examined for the same time period. This analysis revealed a skewness of up to several hours in portions of the data. These hourly data were recorded by the energy monitoring project in about 2-week intervals, but the skewness could not be evaluated in each 2-week data period because of the data collection procedure. Thus, comparisons of predicted vs measured data were deemed valid only for intervals of 2 weeks or longer. Hourly or daily comparisons could not be made. Predicted vs measured total electrical consumption data for the period 15 March to 31 July 1980 is in Table 4. Comparison results show that BLAST-predicted total building electrical consumption for the entire simulation period: the predicted electrical consumption is consistently too high throughout the simulation period. These results agree with the results of the short-term simulation of the dental clinic.

Predicted vs measured total gas consumption for the period 15 March to 31 July 1980 is in Table 5. BLAST-predicted total building gas consumption is 11.7 percent lower than measured total building gas consumption for the entire simulation period. As the results for the comparisons by 2-week intervals show, the predicted gas consumption is too low during the spring months and too high during the summer months. This indicates that the part-load operation of the boiler is not as simulated by BLAST. The default part-load curve, which was used to model the clinic's boiler, appears to underpredict the boiler's gas consumption at high part-load operation, and overpredict the boiler's gas consumption at low part-load operation.

Table 4

Dental Clinic Simulation -- Long Time Period
Electrical Data Comparison

Total Building Electrical	Measured (kWh)	Predicted (kWh)	% Difference
15 March to 31 July	175,738	194,390	10.61
15 March to 31 March	10,661	20,620	-93.42
01 April to 15 April	15,944	18,270	-14.59
16 April to 30 April	17,818	18,580	-4.28
01 May to 15 May	22,000	19,389	+11.87
15 May to 31 May	21,170	21,871	-3.31
01 June to 15 June	20,911	21,429	-2.48
16 June to 30 June	20,638	24,520	-18.81
01 July to 15 July	22,094	24,316	-10.06
16 July to 31 July	24,502	25,393	-3.64

Table 5

Dental Clinic Simulation -- Long Time Period

Gas Data Comparison

Total Building Gas	Measured (kWh)	Predicted (kWh)	% Difference
15 March to 31 July	82,515	72,851	+11.71%
15 March to 31 March	11,501	14,650	-27.38%
01 April to 15 April	18,593	12,085	+35.00%
16 April to 30 April	13,420	11,322	+15.63%
01 May to 15 May	13,450	10,067	+25.15%
16 May to 31 May	11,316	7,823	+30.87%
01 June to 15 June	5,129	5,451	-6.28%
16 June to 30 June	3,071	3,760	-22.44%
01 July to 15 July	2,658	3,467	-30.44%
16 July to 31 July	3,376	3,956	-17.18%

Summary

BLAST predicted the energy performance of the dental clinic to within 10 to 12 percent. Because the energy consumption of the dental clinic is dominated by the energy consumption of the HVAC equipment, these results indicate that BLAST is accurately modeling the performance of the multizone fan system and the chiller package. Even in the complicated case where the multizone system is supplied with both heating and cooling, BLAST predicts the total energy consumption to within 12 percent.

The load profile used to predict internal building electrical loads could be revised to improve the accuracy of the BLAST prediction. Analysis of the measured internal electrical consumption data, however, indicates that the baseline internal building electrical consumption for nights and weekends fluctuates irregularly. Thus, it would be very difficult to accurately predict a single profile for the clinic's internal electrical consumption. Because of the size of the facility, even small fluctuations in this demand can cause relatively large errors in predicted vs measured data.

Improvements could be made in the input used to describe the dental clinic's chiller package performance. The default full-load power ratio adjustment curve as input to the BLAST program could be revised to more accurately reflect actual chiller operation; also, the part-load ratio curve could be modified at the higher load conditions to more accurately reflect actual consumption. (It would be difficult to accurately determine these parameters, since the system did not operate at full load during the simulation/monitoring period.)

The actual part-load ratio curve for the boiler could be included in the input to more accurately reflect the boiler's operation. Determination of this curve would require detailed measurements of the boiler operation. (These measurements could not be made during the detailed monitoring period, since the hot water supply pump was out of service.)

Other revisions could be made to the simulation input deck to achieve more accurate predictions; if exact input information is available, BLAST should be able to accurately predict the building's energy consumption.

4 ANALYSES AND FINDINGS -- BATTALION HEADQUARTERS AND CLASSROOM BUILDING

BLAST Input Deck

The first floor of the battalion headquarters and classroom building was divided into nine simulation zones. These simulation zones corresponded to the seven zones served by the building's multizone air handler and the two zones served by the building's unit heaters (Figure 3). The basement floor of the facility was modeled as a single zone served by a single zone draw-through system (as shown in the as-built drawings). Zone geometries and construction details of the walls, roof, floors, and ceiling were determined from the construction drawings. The electrical load profiles for the building and the peak building internal electrical demand were determined by analyzing data supplied by the contractor (Figure 10). Peak electrical demand for each zone was estimated from a disaggregation of the peak internal building electrical demand. Building occupancy was determined from occupant questionnaires. The occupancy profile for the building was estimated by the contractor (Figure 11). Zone peak occupancy (estimated from building use patterns), zone thermostat settings, and control profiles were determined from the contractor-supplied data.

Information about the fan system was obtained from construction drawings, the HVAC control diagrams, control specifications, and contractor-measured data. Because this facility is supplied by a large central boiler/chiller plant which serves many buildings, a mechanical plant was not simulated.

The basement HVAC system operation could not be simulated exactly. In the actual system, the fan runs only when the outside air dry-bulb temperature is below 25.56°C. In the BLAST simulation, the fan runs whenever there is a demand for heating. Thus, the BLAST model probably simulates the system for more hours than the actual system operates.

The BLAST input deck for the battalion headquarters and classroom building is in Appendix B.

Computer Simulation -- Short Time Period

Actual weather data were obtained from the Army's energy monitoring project for the period 1 August to 6 September 1978 and a BLAST simulation of the battalion headquarters and classroom building was performed for this period. The hourly data available from the simulation included total building boundary, and internal building and fan system electrical consumption. BLAST also predicted the building's hourly hot and chilled water consumption.

Comparison of Data -- Short Time Period

The results of the BLAST simulation are in Table 6. The prediction for total building electrical consumption for the entire simulation period is 5.2 percent lower than the measured total building electrical consumption. The correlation coefficient for the week of 6 to 12 August 1978 is 0.93.

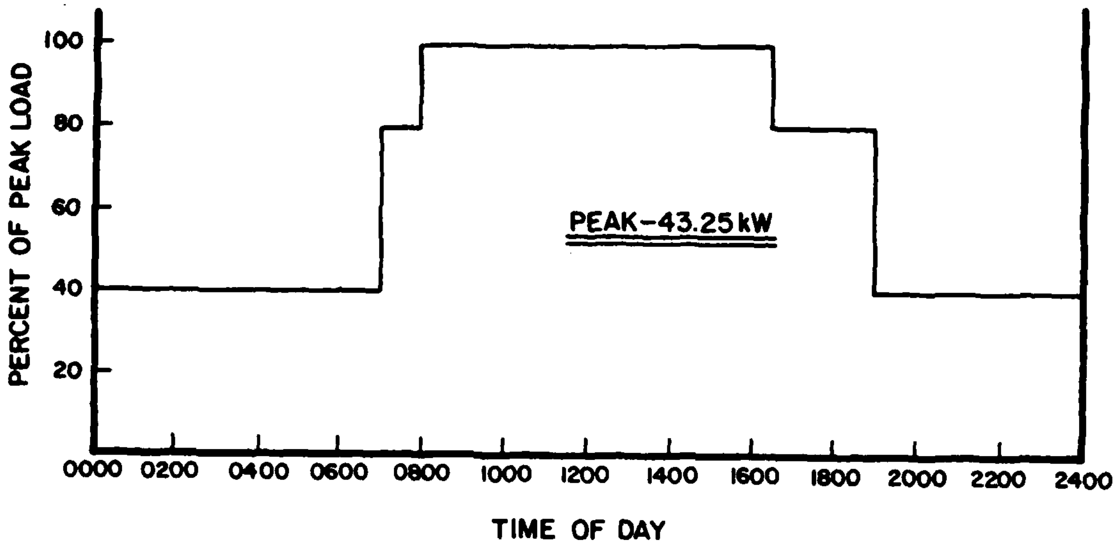

Figure 10. Battalion headquarters and classroom building internal load profile.

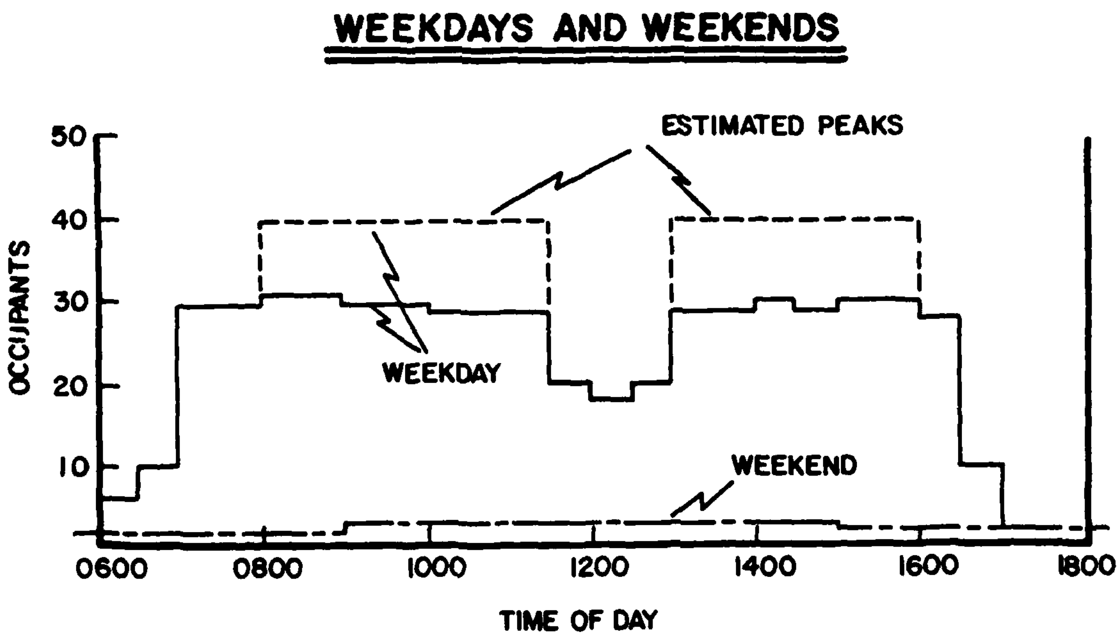

Figure 11. Battalion headquarters and classroom building occupancy profile.

Table 6

Battalion Headquarters Simulation -- Short Time Period

Electrical Data Comparison

Total Building Electrical	Measured (kWh)	Predicted (kWh)	% Difference
1 August to 6 September 1978	20,952.9	19,910	+5.24

Statistics (hourly)* for 6 to 12 August 1978	Total Building Electrical
R**	0.93
DIFFFAVE (kWh)	-0.89
DIFFVAR	5.06
DIFFSTD	2.25
PERAVE	-1.16
PERVAR	78.71
PERSTD	8.87
DABSAVE	1.561
DABSVAR	2.619
DABSSTD	1.618

* See Appendix C for definition of statistics
**Correlation coefficient

Computer Simulation -- Long Time Period

While the short-term simulation was indicative of the accuracy of the battalion headquarters and classroom building simulation model, comparison for a longer time period, including both the heating and cooling season, was desirable. Because the typical BLAST user does not have access to actual onsite weather data for his/her simulation, it was decided to use weather data from the closest National Weather Service recording station -- Colorado Springs, CO. Energy data were available from the Army's energy monitoring project for the periods 6 December 79 to 8 April 1980 and 23 Apr to 15 June 1980. (No data were available for the period 9 to 22 April 1980 because of an instrumentation failure.) Weather data were obtained for Colorado Springs, CO for the period 6 December 1979 to 15 June 1980, and using the battalion headquarters input deck, a BLAST simulation was performed for this period. The simulation predicted the hourly total electrical consumption, which included the building's internal and fan system electrical consumption, and the hourly hot and chilled water consumption for the building.

Comparison of Data -- Long Time Period

After the simulation was completed and the energy data from the Army's energy monitoring project were examined for the same time period, several problems were identified. The measured data were to have included hourly building boundary electrical, hot water, and chilled water consumption data. (The hot and chilled water consumption was determined by measuring the supply and return temperatures and the mass flow rate of the water.) But because the temperature instrumentation for the chilled water consumption measurement failed, no data were available for chilled water consumption for the entire period. However, as determined by a building survey, the chilled water supply pump for the building was shut off during the entire simulation period; thus, no chilled water was used by the battalion headquarters during the simulation period.

Analysis of the measured hot water data revealed that the building's hot water energy consumption was measured inaccurately. During the heating season, the hot water mass flow rate to the building should be more or less constant. But as Figure 12 shows, the measured hot water mass flow rate varied sporadically during the heating season. Figure 13 shows that the hot water supply temperature varied during the same period. These variations caused the measured hot water energy consumption to be less than the actual consumption. Because the hot water supply temperature is reset according to the outside air dry-bulb temperature, it is difficult to determine the magnitude of the error in the measured data. However, analysis of the data for the 6th, 7th, and 8th of January 1980 shows that the measured data underaccounts for the hot water energy consumption by 20 to 30 percent.

Analysis of the measured electrical consumption data revealed a skewness in the hourly data. Hourly data were collected by the monitoring project in about 2-week intervals; several hours skewness was identified in some of these intervals. The skewness could not be evaluated in other 2-week periods because of the data collection procedure. Because of this skewness, only comparisons of predicted vs measured data for the total 2-week periods were deemed valid. Hourly or daily comparisons could not be made.

Predicted vs measured building boundary electrical consumption is in Table 7. Comparison results show that for the total simulation period, the predicted electrical consumption is 10.4 percent higher than the measured electrical consumption. As the comparison for the 2-week intervals shows, the predicted electrical consumption is consistently too high. Since detailed measurements of electrical consumption data were not available, it was difficult to analyze the potential errors in the simulation. Two possible sources of error were (1) a change in the building's use pattern, which would make the internal electrical profile incorrect, and (2) the incorrect simulation of the basement fan system. Either of these errors could have caused BLAST to overpredict the building's electrical consumption.

Predicted vs measured building boundary hot water consumption is in Table 8. The comparison shows that for the total simulation period, the predicted hot water consumption is 48.7 higher than the measured hot water consumption. Because detailed measurements of hot water consumption for each individual fan system were not available, it was difficult to determine the cause of this error. A large percentage of this error (20 to 30 percent) could be the

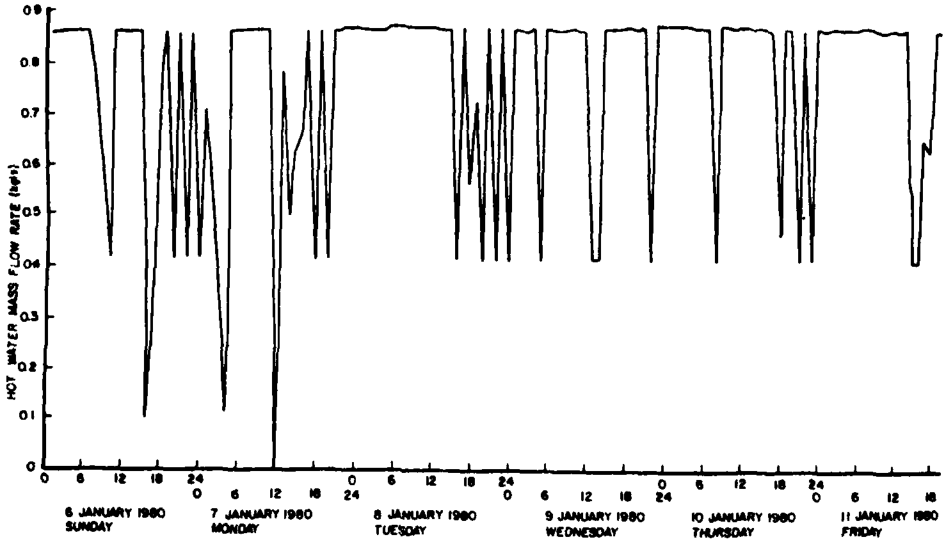

Figure 12. Battalion headquarters measured hot water mass flow rate.

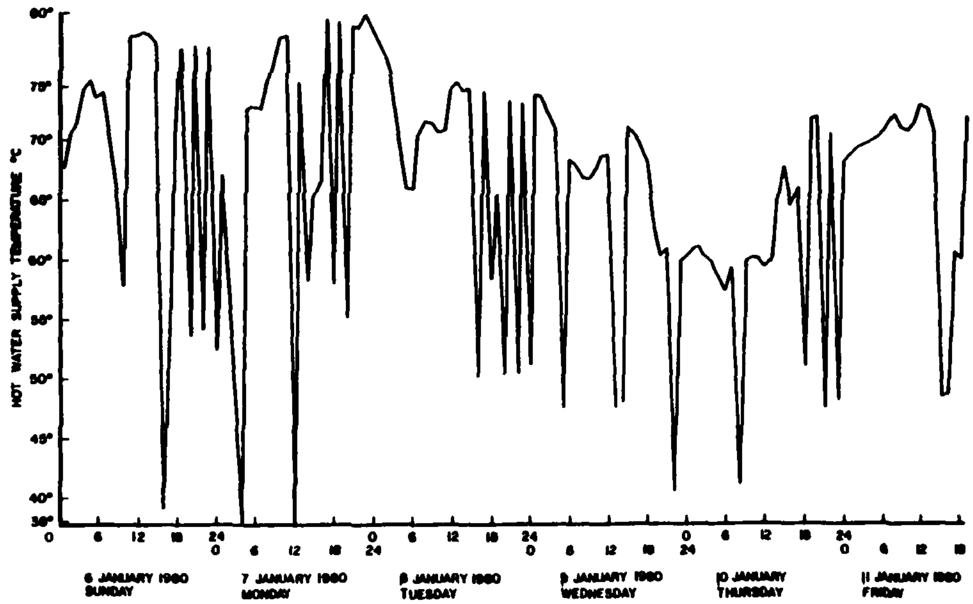

Figure 13. Battalion headquarters measured hot water supply temperatures.

result of inaccurate measured data. As the 2-week data in Table 8 show, agreement is much worse in the May to June period. This is probably caused by the inaccurate simulation of the basement fan system. Thermostat settings in the building that differed from those simulated and a multizone HVAC system that operated differently from the one simulated could have also caused disagreement.

Summary

BLAST predicted the electrical energy consumption of the battalion headquarters and classroom building to within 10 percent, but the BLAST input deck could be revised to make its predictions more reliable. Because the building's electrical consumption is dominated by its internal consumption, a more accurate internal electrical consumption profile could be developed. Since the building is a battalion headquarters, however, it is occupied by a small staff at night and on weekends. Analysis of the measured data has shown that night and weekend electrical consumption is a direct function of the efforts the night and weekend staff make toward energy conservation. Because of the facility's size, this effect has a significant impact on the total electrical consumption and makes the determination of a single internal electrical profile for a long time period very difficult.

Revisions could be made to the fan system input deck to more accurately reflect the fan system's electrical consumption, but it is probably impossible to significantly improve the accuracy of the BLAST fan system electrical prediction without revising BLAST's simulation capabilities to allow for an exact simulation of the basement fan system.

The agreement between BLAST-predicted and measured hot water consumption for this building was very poor (49 percent). Analysis of the measured data reveals that a significant fraction of that error could be the result of inaccurate measurement. Thus, it is impossible to determine exactly what revisions (if any) are needed in the BLAST input deck.

Table 7

Battalion Headquarters and Classroom Building Simulation -- Long Time Period Electrical Data Comparison

Total Electrical Consumption	Measured (kWh)	Predicted (kWh)	% Difference
6 December 1979 to 8 April 1980 and 23 April to 22 July 1980	104,651	115,485	10.4
16 to 31 December 1979	8,041	10,190	26.7
1 to 15 January 1980	8,797	9,648	9.7
16 to 31 January 1980	9,689	10,483	8.2
1 to 15 February 1980	9,163	9,789	6.8
16 to 29 February 1980	8,379	8,961	7.0
1 to 15 March 1980	8,192	9,648	17.8
16 to 31 March 1980	9,713	10,342	6.5
1 March to 15 May 1980	9,683	10,135	4.7
16 March to 31 May 1980	9,195	9,791	6.5
1 to 15 June 1980	8,443	9,544	13.0

Table 8

Battalion Headquarters and Classroom Building Simulation -- Long Time Period Hot Water Data Comparison

Total Hot Water Consumption	Measured (kWh)	Predicted (kWh)	% Difference
6 December 1979 to 8 April 1980 and 23 April to 22 July 1980	737,997	1,097,859	48.7
16 to 31 December 79	83,517	115,118	37.8
1 to 15 January 1980	71,292	108,411	52.1
16 to 31 January 1980	84,375	138,574	64.2
1 to 15 February 1980	67,522	110,286	63.3
16 to 29 February 1980	66,827	88,233	32.0
1 to 15 March 1980	70,979	96,297	35.7
16 to 31 March 1980	81,059	107,995	33.2
1 to 15 May 1980	43,993	75,900	72.5
16 to 31 May 1980	28,730	62,170	116.4
1 to 15 June 1980	21,586	39,856	84.6

5 GENERAL RESULTS

The analyses described in Chapters 3 and 4 indicate that it is very difficult to compare predicted energy-use data obtained from an energy analysis computer program with measured energy-use data. As discussed in Chapter 2, a building's actual energy use is partially determined by factors which cannot be accurately described to a computer analysis program. For example, the occupant effects on lighting use, window and door openings, and thermostat settings are highly variable over a long time period and cannot be defined for a building without extensive monitoring. The actual operation of the HVAC control system over a long time period is also very difficult to determine.

As the analyses in this report illustrate, obtaining consistent and reliable building boundary energy-use data is also difficult, especially if it is necessary to measure hot and chilled water energy use. Building boundary energy data are sufficient only for determining if the computer program's total energy predictions are correct. To determine the accuracy of each portion of the simulation, detailed measurements of each building component's operation and energy use, including occupant effects, must be made. Outside of a controlled laboratory environment, these measurements are extremely difficult.

Within these constraints, the agreement between the BLAST-predicted and measured energy use for the two buildings analyzed during this study is very good. BLAST predicted the total energy consumption of the dental clinic (including electricity and gas consumption) to within 10 to 12 percent and the electrical energy consumption of the battalion headquarters and classroom building to within 10 percent when accurate simulation models were used. However, this agreement can be improved only if an extensive monitoring effort was undertaken for each building.

6 CONCLUSIONS

1. To compare actual building energy use with energy use predicted by an energy analysis computer program such as BLAST, accurate, concurrent hourly measurements of weather data, energy-use data, occupancy-dependent parameters, and equipment operating parameters must be obtained. These data are typically very difficult to collect outside a laboratory environment.

2. Within the constraints of available, accurate measured data for the typical Army buildings analyzed in this study, the BLAST energy analysis computer program can successfully predict building boundary energy consumption, including both electrical and gas consumption, to within 10 to 12 percent when accurate input is made to the program.

3. BLAST can accurately predict electrical consumption of a chiller package for the typical Army buildings analyzed in this study. The chiller's predicted vs actual curve (Figure 13) confirms the validity of modeling cooling components on an hourly time step. The chiller simulation actually models the average performance of the component over the hour, while the real chiller cycles during a much smaller time step. The predicted and actual curves show BLAST's modeling validity and its sensitivity to changes in the part-load ratios and full-load power of a chiller package.

4. When an energy analysis program such as BLAST is used to evaluate design alternatives, most of the hard-to-define effects of building occupants on building energy use are constant and therefore relatively unimportant. When the program is used to predict the actual energy performance of a building, values for building geometry, materials, schedules, controls, and HVAC systems must be precise and consistent and the effects of occupants on the building's energy use must be carefully described to the program.

APPENDIX A:

DENTAL CLINIC SIMULATION MODEL

Dental Clinic Simulation Model

```
BEGIN INPUT;
RUN CONTROL:  NEW ZONES,
              NEW AIR SYSTEMS,
           CENTRAL PLANT,
  UNITS(OUT=METRIC);
TEMPORARY LOCATION: FT HOOD = (LAT=31,LONG=97.8,TZ=6); END;
TEMPORARY DESIGN DAYS:
      FT HOOD WINTER = (HIGH=32,LOW=20,WEEKEND,WB=20,DATE=21JAN),
      FT HOOD SUMMER = (HIGH=106,LOW=84,WB=85,DATE=21JUL,PRES=405,
                  CLEARNESS=.95,WEEKDAY); END;
TEMPORARY SCHEDULE (ALL ZONES PEOPLE):
      MONDAY THRU FRIDAY = (17 TO 07 - 0,,.5,.94,.92,.79,.52,.56,.75,
                       .68,.61,.28),
      SATURDAY THRU SUNDAY = (00 TO 24 - 0),
      HOLIDAY = SUNDAY;
END;
TEMPORARY SCHEDULE (CLINIC LIGHTS AND EQUIPMENT):
 MONDAY THRU FRIDAY = (19 TO 07 - .34,.58,.98,.98,.98,.86,
                      .72,.91,.98,.95,.79,.40,.40),
      SATURDAY THRU SUNDAY = (00 TO 24 - .34),
      HOLIDAY = SUNDAY;
END;
TEMPORARY CONTROLS (CLINIC CONTROLS):
      PROFILES:
        CONSTANT = (1 AT 66, 0 AT 68, -.125 AT 70, -1 AT 140);
      SCHEDULES:
         MONDAY THRU SUNDAY = (00 TO 24 - CONSTANT),
         HOLIDAY = SUNDAY;
END;
TEMPORARY WALLS:
      EWALL1 = (BRICK - FACE 4 IN,
                CONCRETE - CEMENT MORTAR 1/2 IN,
                CONCRETE - CEMENT MORTAR 1/2 IN,
                CONCRETE - CEMENT MORTAR 1/2 IN,
                CONCRETE - CEMENT MORTAR 1/2 IN,
                C3 - 4 IN HW CONCRETE BLOCK,
                B1 - AIRSPACE RESISTANCE,
                BUILDING BOARD - GYPSUM PLASTER 1 / 2 IN),
      PWALL1 = (BUILDING BOARD - GYPSUM PLASTER 1 / 2 IN,
                B1 - AIRSPACE RESISTANCE,
                BUILDING BOARD - GYPSUM PLASTER 1 / 2 IN),
      PWALL2 = (C8 - 8 IN HW CONCRETE BLOCK,
                B1 - AIRSPACE RESISTANCE,
                BUILDING BOARD - GYPSUM PLASTER 1 / 2 IN),
      CPWALL = (A1 - 1 IN STUCCO,
                C10 - 8 IN HW CONCRETE,
                E1 - 3 / 4 IN PLASTER OR GYP BOARD);
END;
TEMPORARY ROOFS:
      ROOF1 = (E2 - 1/ 2 IN SLAG OR STONE,
               E3 - 3/8 IN FELT AND MEMBRANE,
               A3 - STEEL SIDING,
               E4 - CEILING AIRSPACE,
               B4 - 3 IN INSULATION,
               E5 - ACOUSTIC TILE),
      CPCEIL =(FINISH FLOORING - TILE 1/16 IN,
               C10 - 8 IN HW CONCRETE,
               B1 - AIRSPACE RESISTANCE,
               B2 - 1 IN INSULATION));
END;
```

Note: The line numbers are NOT a part of the BLAST input requirements. They have been added for convenience.

```
TEMPORARY FLOORS:
      FLOOR1 = (B2 - 1 IN INSULATION,
                B1 - AIRSPACE RESISTANCE,
                C10 - 8 IN HW CONCRETE,
                FINISH FLOORING - TILE 1/16 IN),
      CPFLOOR = (DIRT 12 IN);
END;
TEMPORARY DOORS:
      WINDOW PANEL = (GLASS - HEAT ABSORBING PLATE 1/ 2 IN,
                      INSULATION - CELLULAR GLASS 2 IN,
                      C3 - 4 IN HW CONCRETE BLOCK,
                      BUILDING BOARD - GYPSUM PLASTER 1 / 2 IN);
END;
PROJECT = "FT HOOD DENTAL CLINIC";
LOCATION= FT HOOD;
 WEATHER TAPE FROM 01 JUN 78 THRU 06 JUL 78;
GROUND TEMPERATURES = (62,61,62,65,68,71,75,75,71,68,65,62);
BEGIN BUILDING DESCRIPTION;
      NORTH AXIS = 0.;
      DIMENSIONS: HEIGHT1 = 9.;
CRAWL SPACE 1000 "CRAWL SPACE":
      ORIGIN:(0,0,-2.5);
      NORTH AXIS = 0;
   CRAWL SPACE CEILING:
      STARTING AT (0,0,2.5) FACING (180) CPCEIL (92 BY 102);
   SLAB ON GRADE FLOOR:
      STARTING AT (0,102,0) FACING (180) CPFLOOR (92 BY 102);
   BASEMENT WALLS:
      STARTING AT (0,0,0) FACING (180) CPWALL (92 BY 2.5),
      STARTING AT (92,0,0) FACING (90) CPWALL (102 BY 2.5),
      STARTING AT (92,102,0) FACING (0) CPWALL (92 BY 2.5),
      STARTING AT (0,102,0) FACING (270) CPWALL (102 BY 2.5);
END ZONE;
ZONE 1 "NORTH LAB":
      ORIGIN:(14,83,0);
      NORTH AXIS = 0;
   EXTERIOR WALLS:
      STARTING AT (31,19.,0) FACING (0) EWALL1 (31 BY HEIGHT1)
         WITH WINDOWS OF TYPE SINGLE PANE TINTED WINDOW
            (6.66 BY 4.25) AT (10,4)
         WITH DOORS OF TYPE WINDOW PANEL
            (6.66 BY 4.0) AT (10,0)
         WITH WINDOWS OF TYPE SINGLE PANE TINTED WINDOW
            (3.33 BY 4.25) AT (27.5,4)
         WITH DOORS OF TYPE WINDOW PANEL
            (3.33 BY 4.0) AT (27.5,0)
         WITH OVERHANGS (50 BY 3) AT (-10,HEIGHT1);
   PARTITIONS:
      STARTING AT (31,0,0) FACING (90) PWALL2 (19. BY HEIGHT1),
      STARTING AT (0,0,0) FACING (180) PWALL1 (31 BY HEIGHT1),
      STARTING AT (0,19.,0) FACING (270) PWALL1 (19 BY HEIGHT1);
   ROOFS:
      STARTING AT (0,0,HEIGHT1) FACING (180) ROOF1 (31 BY 19.);
   FLOOR OVER CRAWL SPACE:
      STARTING AT (0,19.,0) FACING (180) FLOOR1 (31 BY 19.);
      PEOPLE = 4,ALL ZONES PEOPLE;
      ELECTRIC EQUIPMENT = 10.24,CLINIC LIGHTS AND EQUIPMENT;
      LIGHTS = 5.73,CLINIC LIGHTS AND EQUIPMENT;
      CONTROLS = CLINIC CONTROLS, 104 HEATING, 154.1 COOLING;
END ZONE;
```

```
ZONE 2 "NORTH WEST LAB":
      ORIGIN:(0,83,0);
      NORTH AXIS = 0;
   EXTERIOR WALLS:
      STARTING AT (0,0,0) FACING (180) EWALL1 (4 BY HEIGHT1)
         WITH OVERHANGS (7 BY 83) AT (-3,HEIGHT1)
         WITH WINGS (HEIGHT1 BY 83) AT (4,0),
      STARTING AT (0,19,0) FACING (270) EWALL1 (19 BY HEIGHT1)
         WITH OVERHANGS (108 BY 3) AT (-3,HEIGHT1),
      STARTING AT (14,19,0) FACING (0) EWALL1 (14 BY HEIGHT1)
         WITH WINDOWS OF TYPE SINGLE PANE TINTED WINDOW
            (3.33 BY 4.25) AT (.5,4)
         WITH DOOR OF TYPE WINDOW PANEL
            (3.33 BY 4.0) AT (.5,0)
         WITH OVERHANGS (60 BY 3) AT (-42,HEIGHT1);
   PARTITIONS:
      STARTING AT (14,6.5,0) FACING (90) PWALL1 (11.5 BY HEIGHT1),
      STARTING AT (4,0,0) FACING (180) PWALL1 (10 BY HEIGHT1);
   ROOFS:
      STARTING AT (0,0,HEIGHT1) FACING (180) ROOF1 (14 BY 19);
   FLOOR OVER CRAWL SPACE:
      STARTING AT (0,19,0) FACING (180) FLOOR1 (14 BY 19);
   PEOPLE = 2,ALL ZONES PEOPLE;
   LIGHTS = 2.18,CLINIC LIGHTS AND EQUIPMENT;
  ELECTRIC EQUIPMENT = 6.82,CLINIC LIGHTS AND EQUIPMENT;
  GAS EQUIPMENT = 5,CLINIC LIGHTS AND EQUIPMENT;
   CONTROLS = CLINIC CONTROLS, 23.68 HEATING, 35.1 COOLING;
END ZONE;
ZONE 3 "WEST OPER RMS":
      ORIGIN:(0,13,0);
      NORTH AXIS = 0.;
   EXTERIOR WALLS:
      STARTING AT (0,70,0) FACING (270) EWALL1 (70 BY HEIGHT1)
         WITH WINDOWS OF TYPE SINGLE PANE TINTED WINDOW
            (5 BY 8.9) REVEAL (3.67) AT (.5,0.05)
         WITH OVERHANGS (87  BY 3) AT (-16,HEIGHT1)
         WITH WINDOWS OF TYPE SINGLE PANE TINTED WINDOW
            (6.66 BY 4.25) AT (13,4)
         WITH DOORS OF TYPE WINDOW PANEL
            (6.66 BY 4.0) AT (13,0)
         WITH WINDOWS OF TYPE SINGLE PANE TINTED WINDOW
            (6.66 BY 4.25) AT (33,4)
         WITH DOORS OF TYPE WINDOW PANEL
            (6.66 BY 4.0) AT (33,0)
         WITH WINDOWS OF TYPE SINGLE PANE TINTED WINDOW
            (6.66 BY 4.25) AT (53,4)
         WITH DOORS OF TYPE WINDOW PANEL
            (6.66 BY 4.0) AT (53,0);
   PARTITIONS:
      STARTING AT (0,0,0) FACING (180) PWALL1 (19 BY HEIGHT1),
      STARTING AT (19,5,0) FACING (90) PWALL1 (59 BY HEIGHT1),
      STARTING AT (19,70,0) FACING (0) PWALL1 (19 BY HEIGHT1);
   ROOFS:
      STARTING AT (0,0,HEIGHT1) FACING (180) ROOF1 (19 BY 70);
   FLOOR OVER CRAWL SPACE:
      STARTING AT (0,70,0) FACING (180) FLOOR1 (19 BY 70);
   PEOPLE = 11,ALL ZONES PEOPLE;
   LIGHTS = 7.14,CLINIC LIGHTS AND EQUIPMENT;
   ELECTRIC EQUIPMENT = 3.41,CLINIC LIGHTS AND EQUIPMENT;
   CONTROLS = CLINIC CONTROLS, 117 HEATING, 173.7 COOLING;
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END ZONE;
ZONE 4 "LOCKER RMS";
      ORIGIN:(18,19,0);
      NORTH AXIS = 0.;
   PARTITIONS:
      STARTING AT (0,0,0) FACING (180) PWALL1 (13 BY HEIGHT1),
      STARTING AT (13,0,0) FACING (90) PWALL1 (59 BY HEIGHT1),
      STARTING AT (13,59,0) FACING (0) PWALL1 (13 BY HEIGHT1),
      STARTING AT (0,59,0) FACING (270) PWALL1 (59 BY HEIGHT1);
   ROOFS:
      STARTING AT (0,0,HEIGHT1) FACING (180) ROOF1 (13 BY 59);
   FLOOR OVER CRAWL SPACE:
      STARTING AT (0,59,0) FACING (180) FLOOR1 (13 BY 59);
   PEOPLE = 2,ALL ZONES PEOPLE;
   LIGHTS = 3.96,CLINIC LIGHTS AND EQUIPMENT;
   ELECTRIC EQUIPMENT = 0,CLINIC LIGHTS AND EQUIPMENT;
   CONTROLS = CLINIC CONTROLS, 44.4 HEATING, 65.8 COOLING;
END ZONE;
ZONE 5 "LIBRARY CONF RMS";
      ORIGIN:(31,47,0);
      NORTH AXIS = 0;
   PARTITIONS:
      STARTING AT (0,0,0) FACING (180) PWALL1 (6 BY HEIGHT1),
      STARTING AT (6,0,0) FACING (90) PWALL1 (3 BY HEIGHT1),
      STARTING AT (6,3,0) FACING (180) PWALL1 (12 BY HEIGHT1),
      STARTING AT (18,3,0) FACING (90) PWALL1 (29 BY HEIGHT1),
      STARTING AT (18,36,0) FACING (0) PWALL1 (30 BY HEIGHT1),
      STARTING AT (-12,36,0) FACING (270) PWALL1 (6 BY HEIGHT1),
      STARTING AT (-12,30,0) FACING (180) PWALL1 (12 BY HEIGHT1),
      STARTING AT (0,30,0) FACING (270) PWALL1 (30 BY HEIGHT1);
   ROOFS:
      STARTING AT (0,0,HEIGHT1) FACING (180) ROOF1 (6 BY 3),
      STARTING AT (0,3,HEIGHT1) FACING (180) ROOF1 (18 BY 33),
      STARTING AT (-12,30,HEIGHT1) FACING (180) ROOF1 (12 BY 6);
   FLOORS OVER CRAWL SPACE:
      STARTING AT (0,3,0) FACING (180) FLOOR1 (6 BY 3),
      STARTING AT (0,36,0) FACING (180) FLOOR1 (18 BY 33),
      STARTING AT (-12,36,0) FACING (180) FLOOR1 (12 BY 6);
   PEOPLE = 4,ALL ZONES PEOPLE;
   LIGHTS = 3.28,CLINIC LIGHTS AND EQUIPMENT;
   ELECTRIC EQUIPMENT = 3.41,CLINIC LIGHTS AND EQUIPMENT;
   CONTROLS = CLINIC CONTROLS, 29.3 HEATING, 43.4 COOLING;
END ZONE;
ZONE 6 "WAITING ROOM";
      ORIGIN:(19,13,0);
      NORTH AXIS = 0.;
   PARTITIONS:
      STARTING AT (0,0,0) FACING (180) PWALL1 (42 BY HEIGHT1),
      STARTING AT (42,5.5,0) FACING (0) PWALL1 (12 BY HEIGHT1),
      STARTING AT (30,5.5,0) FACING (90) PWALL1 (31 BY HEIGHT1),
      STARTING AT (30,36.5,0) FACING (0) PWALL1 (12 BY HEIGHT1),
      STARTING AT (18,36.5,0) FACING (270) PWALL1 (3 BY HEIGHT1),
      STARTING AT (18,33.5,0) FACING (0) PWALL1  (6 BY HEIGHT1),
      STARTING AT (12,33.5,0) FACING (270) PWALL1 (28 BY HEIGHT1),
      STARTING AT (12,5.5,0) FACING (0) PWALL1 (12 BY HEIGHT1);
   ROOFS:
      STARTING AT (0,0,HEIGHT1) FACING (180) ROOF1 (42 BY 5.5),
      STARTING AT (12,5.5,HEIGHT1) FACING (180) ROOF1 (18 BY 28),
      STARTING AT (18,33.5,HEIGHT1) FACING (180) ROOF1 (12 BY 3);
   FLOORS OVER CRAWL SPACE:
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        STARTING AT (0,5.5,0) FACING (180) FLOOR1 (42 BY 5.5),
        STARTING AT (12,33.5,0) FACING (180) FLOOR1 (18 BY 28),
        STARTING AT (18,36.5,0) FACING (180) FLOOR1 (12 BY 3);
     PEOPLE = 31,ALL ZONES PEOPLE;
     LIGHTS = 2.73,CLINIC LIGHTS AND EQUIPMENT;
     ELECTRIC EQUIPMENT = 1.82,CLINIC LIGHTS AND EQUIPMENT;
     CONTROLS = CLINIC CONTROLS, 48.6 HEATING, 72.0 COOLING;
  END ZONE;
  ZONE 7 "RECORDS AND SUPPLY":
        ORIGIN:(49,18.5,0);
        NORTH AXIS = 0.;
     PARTITIONS:
        STARTING AT (0,0,0) FACING (180) PWALL1 (12 BY HEIGHT1),
        STARTING AT (12,0,0) FACING (90) PWALL1 (45 BY HEIGHT1),
        STARTING AT (12,45,0) FACING (180) PWALL1 (6 BY HEIGHT1),
        STARTING AT (18,45,0) FACING (90) PWALL1 (13 BY HEIGHT1),
        STARTING AT (18,58,0) FACING (180) PWALL1 (7 BY HEIGHT1),
        STARTING AT (25,64.5,0) FACING (0) PWALL2 (25 BY HEIGHT1),
        STARTING AT (0,64.5,0) FACING (270) PWALL1 (64.5 BY HEIGHT1);
     ROOFS:
        STARTING AT (0,0,HEIGHT1) FACING (180) ROOF1 (12 BY 64.5),
        STARTING AT (12,45,HEIGHT1) FACING (180) ROOF1 (6 BY 18.5),
        STARTING AT (18,58,HEIGHT1) FACING (180) ROOF1 (7 BY 5.5);
     FLOORS OVER CRAWL SPACE:
        STARTING AT (0,64.5,0) FACING (180) FLOOR1 (12 BY 64.5),
        STARTING AT (12,64.5,0) FACING (180) FLOOR1 (6 BY 18.5),
        STARTING AT (18,64.5,0) FACING (180) FLOOR1 (7 BY 5.5);
     PEOPLE = 7,ALL ZONES PEOPLE;
     LIGHTS = 4.37,CLINIC LIGHTS AND EQUIPMENT;
     ELECTRIC EQUIPMENT = 3.41,CLINIC LIGHTS AND EQUIPMENT;
     CONTROLS = CLINIC CONTROLS, 51.6 HEATING, 76.4 COOLING;
  END ZONE;
  ZONE 8 "XRAY":
        ORIGIN:(61,13,0);
        NORTH AXIS = 0.;
    PARTITIONS:
        STARTING AT (0,0,0) FACING (180) PWALL1 (16 BY HEIGHT1),
        STARTING AT (16,0,0) FACING (90) PWALL1 (69 BY HEIGHT1),
        STARTING AT (16,69,0) FACING (0) PWALL2 (4 BY HEIGHT1),
        STARTING AT (12,64,0) FACING (0) PWALL1 (7 BY HEIGHT1),
        STARTING AT (5,64,0) FACING (270) PWALL1 (14 BY HEIGHT1),
        STARTING AT (5,50,0) FACING (0) PWALL1 (5 BY HEIGHT1),
        STARTING AT (0,50,0) FACING (270) PWALL1 (45 BY HEIGHT1);
     ROOFS:
        STARTING AT (0,0,HEIGHT1) FACING (180) ROOF1 (16 BY 50),
        STARTING AT (5,50,HEIGHT1) FACING (180) ROOF1 (11 BY 14),
        STARTING AT (12,64,HEIGHT1) FACING (180) ROOF1 (4 BY 5);
     FLOORS OVER CRAWL SPACE:
        STARTING AT (0,50,0) FACING (180) FLOOR1 (16 BY 50),
        STARTING AT (5,64,0) FACING (180) FLOOR1 (11 BY 14),
        STARTING AT (12,69,0) FACING (180) FLOOR1 (4 BY 5);
     PEOPLE = 5,ALL ZONES PEOPLE;
     LIGHTS = 3.96,CLINIC LIGHTS AND EQUIPMENT;
     ELECTRIC EQUIPMENT = 28.87,CLINIC LIGHTS AND EQUIPMENT;
     CONTROLS = CLINIC CONTROLS, 48.3 HEATING, 71.6 COOLING;
  END ZONE;
  ZONE 9 "SOUTH OPER RMS":
        ORIGIN:(0,0,0);
        NORTH AXIS = 0.;
     EXTERIOR WALLS:
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         STARTING AT (0,0,0) FACING (180) EWALL1 (92 BY HEIGHT1)
            WITH WINDOWS OF TYPE SINGLE PANE TINTED WINDOW
               (6.66 BY 4.25) AT (9,4)
            WITH DOORS OF TYPE WINDOW PANEL
               (6.66 BY 4.0) AT (9,0)
            WITH WINDOWS OF TYPE SINGLE PANE TINTED WINDOW
               (6.66 BY 4.25) AT (28,4)
            WITH DOORS OF TYPE WINDOW PANEL
               (6.66 BY 4.0) AT (28,0)
            WITH WINDOWS OF TYPE SINGLE PANE TINTED WINDOW
               (8 BY 8.9) REVEAL (4) AT (42,.05)
            WITH OVERHANGS (98 BY 3) AT (-3,HEIGHT1)
            WITH WINDOWS OF TYPE SINGLE PANE TINTED WINDOW
               (6.66 BY 4.25) AT (58,4)
            WITH DOORS OF TYPE WINDOW PANEL
               (6.66 BY 4.0) AT (58,0)
            WITH WINDOWS OF TYPE SINGLE PANE TINTED WINDOW
               (6.66 BY 4.25) AT (78,4)
            WITH DOORS OF TYPE WINDOW PANEL
               (6.66 BY 4.0) AT (78,0),
         STARTING AT (92,0,0) FACING (90) EWALL1 (13.5 BY HEIGHT1)
            WITH OVERHANGS (100 BY 3) AT (-3,HEIGHT1),
         STARTING AT (0,13.5,0) FACING (270) EWALL1 (13.5 BY HEIGHT1)
            WITH OVERHANGS (100 BY 3) AT (-93.5,HEIGHT1);
      PARTITIONS:
         STARTING AT (92,13.5,0) FACING (0) PWALL1 (92 BY HEIGHT1);
      ROOFS:
         STARTING AT (0,0,HEIGHT1) FACING (180) ROOF1 (92 BY 13.5);
      FLOOR OVER CRAWL SPACE:
         STARTING AT (0,13.5,0) FACING (180) FLOOR1 (92 BY 13.5);
      PEOPLE = 11,ALL ZONES PEOPLE;
      LIGHTS = 9.28,CLINIC LIGHTS AND EQUIPMENT;
      ELECTRIC EQUIPMENT = 3.41,CLINIC LIGHTS AND EQUIPMENT;
      CONTROLS = CLINIC CONTROLS, 130.9 HEATING, 194.0 COOLING;
   END ZONE;
   ZONE 10 "EAST OPER RMS":
         ORIGIN:(77,13,0);
         NORTH AXIS = 0.;
      PARTITIONS:
         STARTING AT (0,0,0) FACING (180) PWALL1 (15 BY HEIGHT1),
         STARTING AT (0,70,0) FACING (270) PWALL1 (70 BY HEIGHT1),
         STARTING AT (15,70,0) FACING (0) PWALL2 (15 BY HEIGHT1);
      EXTERIOR WALLS:
         STARTING AT (15,0,0) FACING (90) EWALL1 (70 BY HEIGHT1)
           WITH WINDOWS OF TYPE SINGLE PANE TINTED WINDOW
               (6.66 BY 4.25) AT (12,4)
            WITH DOORS OF TYPE WINDOW PANEL
               (6.66 BY 4.0) AT (12,0)
            WITH WINDOWS OF TYPE SINGLE PANE TINTED WINDOW
               (6.66 BY 4.25) AT (32,4)
            WITH DOORS OF TYPE WINDOW PANEL
               (6.66 BY 4.0) AT (32,0)
            WITH WINDOWS OF TYPE SINGLE PANE TINTED WINDOW
               (6.66 BY 4.25) AT (51,4)
            WITH DOORS OF TYPE WINDOW PANEL
               (6.66 BY 4.0) AT (51,0)
            WITH WINDOWS OF TYPE SINGLE PANE TINTED WINDOW
               (5 BY 8.9) REVEAL (3.67) AT (65,0)
            WITH OVERHANGS (76 BY 3) AT (-3,HEIGHT1);
      ROOFS:
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        STARTING AT (0,0,HEIGHT1) FACING (180) ROOF1 (15 BY 70);
     FLOOR OVER CRAWL SPACE:
        STARTING AT (0,70,0) FACING (180) FLOOR1 (15 BY 70);
     PEOPLE = 8,ALL ZONES PEOPLE;
     LIGHTS = 6.41,CLINIC LIGHTS AND EQUIPMENT;
     ELECTRIC EQUIPMENT = 3.41,CLINIC LIGHTS AND EQUIPMENT;
     CONTROLS = CLINIC CONTROLS, 122.7 HEATING, 181.9 COOLING;
  END ZONE;
  END BUILDING DESCRIPTION;
  BEGIN FAN SYSTEM DESCRIPTION;
  MULTIZONE SYSTEM 1 "MAIN FAN SYSTEM" SERVING ZONES 1,2,3,4,5,6,7,8,9,10;
  FOR ZONE 1:
        EXHAUST AIR VOLUME = 1000;
        SUPPLY AIR VOLUME = 1784;
  END;
  FOR ZONE 2:
        SUPPLY AIR VOLUME = 406;
  END;
  FOR ZONE 3:
        SUPPLY AIR VOLUME = 2010;
  END;
  FOR ZONE 4:
        EXHAUST AIR VOLUME = 600;
        SUPPLY AIR VOLUME = 761;
  END;
  FOR ZONE 5:
        SUPPLY AIR VOLUME = 502;
  END;
  FOR ZONE 6:
        SUPPLY AIR VOLUME = 833;
  END;
  FOR ZONE 7:
        SUPPLY AIR VOLUME = 884;
  END;
  FOR ZONE 8:
        SUPPLY AIR VOLUME = 829;
  END;
  FOR ZONE 9:
        SUPPLY AIR VOLUME = 2245;
  END;
  FOR ZONE 10:
        SUPPLY AIR VOLUME = 2105;
  END;
  OTHER SYSTEM PARAMETERS:
       SUPPLY FAN EFFICIENCY = .38;
        HOT DECK CONTROL = OUTSIDE AIR CONTROLLED;
        HOT DECK CONTROL SCHEDULE = (120 AT 10, 80 AT 70);
        COLD DECK CONTROL = FIXED SET POINT;
        COLD DECK TEMPERATURE = 60.;
      COLD DECK THROTTLING RANGE = 5;
        MIXED AIR CONTROL = FIXED AMOUNT;
        OUTSIDE AIR VOLUME = 4114.;
  END;
  COOLING COIL DESIGN PARAMETERS:
        COIL TYPE = DX;
        ENTERING AIR DRY BULB TEMPERATURE = 87.6;
        ENTERING AIR WET BULB TEMPERATURE = 70.3;
        LEAVING AIR DRY BULB TEMPERATURE = 61.;
        LEAVING AIR WET BULB TEMPERATURE = 59.;
        AIR FACE VELOCITY = 514.6;
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      AIR VOLUME FLOW RATE = 15760;
      BAROMETRIC PRESSURE = 405;
      LEAVING REFRIGERANT TEMPERATURE=45.;
      ENTERING REFRIGERANT TEMPERATURE = 45;
      TOTAL COOLING LOAD = 600;
      NUMBER OF TUBE CIRCUITS=20;
END;
DX CONDENSING UNIT PARAMETERS;
      RPWRCD(.40349281,.21287191,.39339793);
      DESIGN SATURATED SUCTION TEMPERATURE=40;
      DESIGN SATURATED CONDENSING TEMPERATURE=130;
      DESIGN FULL LOAD POWER RATIO=.351;
      DX CONDENSING UNIT CAPACITY=600;
END DX CONDENSING UNIT PARAMETERS;
END SYSTEM;
END FAN SYSTEM DESCRIPTION;
BEGIN CENTRAL PLANT DESCRIPTION;
     PLANT 1 "BOILER ONLY" SERVING ALL SYSTEMS;
      EQUIPMENT SELECTION;
         1 BOILER OF SIZE 100;
      END EQUIPMENT SELECTION;
     END PLANT;
  END CENTRAL PLANT DESCRIPTION;
END INPUT;
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APPENDIX B:

BATTALION HEADQUARTERS AND CLASSROOM BUILDING SIMULATION MODEL

Battalion Headquarters and Classroom Building Simulation Model

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  BEGIN INPUT;
   RUN CONTROL : NEW ZONES, NEW SYSTEMS, PLANT,
      UNITS(IN=ENGLISH,OUT=ENGLISH),
REPORTS (ZONE LOADS,SYSTEM LOADS,COIL LOADS,SYSTEM,PLANT LOADS,
38);
DEFINE LOCATION:
   FT CARSON = (LAT=38.75,LONG=104.5,TZ=7);
END;
DEFINE DESIGN DAYS:
      FT CARSON SUMMER = (HIGH=92,LOW=61,WB=59,DATE=21JUL,WEEKDAY,PRES=390),
      FT CARSON WINTER = (HIGH=10,LOW=-2,WB=-2,DATE=21JAN,WEEKEND,PRES=390);
END;
TEMPORARY WALLS:
   WALL = (BRICK - FACE 4 IN,
           AIRSPACE - VERTICAL,
           C8 - 8 IN HW CONCRETE BLOCK);
   WALL1= (E1 - 3/4 IN PLASTER OR GYP BOARD,
           AIRSPACE - VERTICAL,
           E1 - 3/4 IN PLASTER OR GYP BOARD),
   WALL2= (C8 - 8 IN HW CONCRETE BLOCK);
END;
TEMPORARY ROOFS:
   ROOF   = (E2 - 1 / 2 IN SLAG OR STONE,
           E3 - 3 / 8 IN FELT AND MEMBRANE,
           B6 - 2 IN DENSE INSULATION,
           A3 - STEEL SIDING,
           B6 - 2 IN DENSE INSULATION,
           E4 - CEILING AIRSPACE,
           E5 - ACOUSTIC TILE);
END;
TEMPORARY CONTROLS (ADMIN COOL AND HEAT):
   PROFILES:
       CANDH = (1 AT 74, 0 AT 76., -0 AT 78);
   SCHEDULES:
       MONDAY THRU SUNDAY = (00 TO 24 - CANDH),
       HOLIDAY = SUNDAY;
END;
TEMPORARY CONTROLS (ADMIN H ONLY):
   PROFILES:
     HONLY = (1 AT 74, 0 AT 76);
   SCHEDULES:
      MONDAY THRU SUNDAY = (00 TO 24 - HONLY),
      HOLIDAY = SUNDAY;
END;
 TEMPORARY SCHEDULE (ADMIN OFFICE OCCUPANCY):
     SATURDAY THRU SUNDAY = (00 TO 24 - .2),
     MONDAY THRU FRIDAY = (17 TO 06 - .2,06 TO 08 - .5,08 TO 12 - 1.0,
                           12 TO 13 - .67,13 TO 17 - 1.);
 END;
 TEMPORARY SCHEDULE (ADMIN CLASSROOM OCCUPANCY):
     SATURDAY THRU SUNDAY = (00 TO 24 - 0.),
     MONDAY THRU FRIDAY = (11 TO 09 - 0.,09 TO 11 - 1.);
 END;
TEMPORARY SCHEDULE (OA VENT):
     SUNDAY THRU SATURDAY = (00 TO 24 - .5);
END;
 TEMPORARY SCHEDULE (OFF):
    SUNDAY THRU SATURDAY = (00 TO 24 - 0.);
 END;
TEMPORARY SCHEDULE (ADMIN LIGHTS):
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  MONDAY THRU FRIDAY = (20 TO 07 - .49,.63,08 TO 18 - 1.,.82,.63),
  SATURDAY THRU SUNDAY = (00 TO 24 - .49),
     HOLIDAY = SUNDAY;
END;
PROJECT = "ADMIN BUILDING";
GROUND TEMPERATURES = (50,52,54,56,60,66,72,69,66,62,58,54);
 WEATHER TAPE FROM 06 DEC THRU 23 JUL;
LOCATION = FT CARSON;
  BEGIN BUILDING DESCRIPTION;
       NORTH AXIS=0.;
    DIMENSIONS; H1=10.75;
ZONE 101 "STORAGE A";
    ORIGIN:(0,0,0);
    NORTH AXIS = 0;
    ROOF;
        STARTING AT (0,0,H1) FACING (180) ROOF (41 BY 77);
    SLAB ON GRADE FLOOR;
        STARTING AT (0,77,0) FACING (180) FLOOR SLAB 4 IN (41 BY 77);
    EXTERIOR WALLS;
        STARTING AT (0,0,0) FACING (180) WALL (41 BY H1),
        STARTING AT (41,77,0) FACING (0) WALL (41 BY H1),
        STARTING AT (0,77,0) FACING (270) WALL (77 BY H1);
    PARTITIONS;
        STARTING AT (41,0,0) FACING (90) WALL1 (77 BY H1);
LIGHTS = 16.59,ADMIN LIGHTS;
PEOPLE = 7,ADMIN OFFICE OCCUPANCY;
CONTROLS = ADMIN H ONLY;
END ZONE;
ZONE 4 "OFFICE A";
    ORIGIN:(41,0,0);
    NORTH AXIS = 0.;
    ROOF;
        STARTING AT (0,0,H1) FACING (180) ROOF(17 BY 10),
        STARTING AT (17,0,H1) FACING (180) ROOF (13 BY 19),
        STARTING AT (30,0,H1) FACING (180) ROOF (28 BY 28);
    SLAB ON GRADE FLOOR;
        STARTING AT (0,10,0) FACING (180) FLOOR SLAB 4 IN (17 BY 10),
        STARTING AT (17,19,0) FACING (180) FLOOR SLAB 4 IN (13 BY 19),
        STARTING AT (30,28,0) FACING (180) FLOOR SLAB 4 IN (28 BY 28);
    EXTERIOR WALLS;
        STARTING AT (0,0,0) FACING (180) WALL (58 BY H1)
           WITH WINDOWS OF TYPE SINGLE PANE WITH BLINDS
           (5.33 BY H1) AT (5,0) AND (26,0) AND (51,0),
        STARTING AT (58,0,0) FACING (90) WALL (20 BY H1);
    PARTITIONS;
        STARTING AT (58,20,0) FACING (90) WALL (8 BY H1),
        STARTING AT (58,28,0) FACING (0)  WALL1 (28 BY H1),
        STARTING AT (30,28,0) FACING (270) WALL1 (9 BY H1),
        STARTING AT (30,19,0) FACING (0) WALL1 (13 BY H1),
        STARTING AT (17,19,0) FACING (270) WALL1 (9 BY H1),
        STARTING AT (17,10,0) FACING (0) WALL1 (17 BY H1),
        STARTING AT (0,10,0) FACING (270) WALL1 (10 BY H1);
    LIGHTS = 6.26,ADMIN LIGHTS;
    CONTROLS = ADMIN COOL AND HEAT;
PEOPLE = 4,ADMIN OFFICE OCCUPANCY;
END ZONE;
ZONE 3 "CONFERENCE A";
    ORIGIN:(41,10,0);
    NORTH AXIS=0;
    ROOF:
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          STARTING AT (0,0,H1) FACING (180) ROOF (17 BY 9),
          STARTING AT (0,9,H1) FACING (180) ROOF (30 BY 14);
      SLAB ON GRADE FLOOR:
          STARTING AT (0,9,0) FACING (180) FLOOR SLAB 4 IN (17 BY 9),
          STARTING AT (0,23,0) FACING (180) FLOOR SLAB 4 IN (30 BY 14);
      PARTITIONS:
          STARTING AT (0,0,0) FACING (180) WALL1 (17 BY H1),
          STARTING AT (17,0,0) FACING (90) WALL1 (9 BY H1),
          STARTING AT (17,9,0) FACING (180) WALL1 (13 BY H1),
          STARTING AT (30,9,0) FACING (90) WALL1 (14 BY H1),
          STARTING AT (30,23,0) FACING (0) WALL1 (30 BY H1),
          STARTING AT (0,23,0) FACING (270) WALL1 (23 BY H1);
          LIGHTS = 2.79,ADMIN LIGHTS;
          CONTROLS = ADMIN COOL AND HEAT;
  PEOPLE = 2,ADMIN OFFICE OCCUPANCY;
  END ZONE;
  ZONE 1 "CLASSROOM A":
      ORIGIN: (41,40,0);
      NORTH AXIS = 0;
      ROOF;
          STARTING AT (0,0,H1) FACING (180) ROOF (70 BY 37);
      SLAB ON GRADE FLOOR:
          STARTING AT (0,37,0) FACING (180) FLOOR SLAB 4 IN (70 BY 37);
      PARTITIONS:
          STARTING AT (0,0,0) FACING (180) WALL2 (70 BY H1),
          STARTING AT (70,0,0) FACING (90) WALL2 (16 BY H1),
          STARTING AT (0,37,0) FACING (270) WALL1 (37 BY H1);
      EXTERIOR WALLS:
          STARTING AT (70,37,0) FACING (0) WALL (70 BY H1);
      WALLS TO UNCOOLED SPACES:
          STARTING AT (70,16,0) FACING (90) WALL2 (21 BY H1);
      LIGHTS = 13.54,ADMIN LIGHTS;
      CONTROLS = ADMIN COOL AND HEAT;
  PEOPLE = 25,ADMIN CLASSROOM OCCUPANCY;
  END ZONE;
  ZONE 2 "HALLWAY":
      ORIGIN:(41,33,0);
      NORTH AXIS = 0;
      ROOF:
          STARTING AT (70,7,H1) FACING (180) ROOF (38 BY 18),
          STARTING AT (0,0,H1) FACING(180) ROOF (30 BY 7),
          STARTING AT (30,-5,H1) FACING (180) ROOF (28 BY 12),
          STARTING AT (58,-13,H1) FACING (180) ROOF (62 BY 20),
          STARTING AT (120,-5,H1) FACING (180) ROOF (28 BY 12),
          STARTING AT (148,0,H1) FACING (180) ROOF (30 BY 7);
      SLAB ON GRADE FLOOR:
          STARTING AT (70,25,0) FACING (180) FLOOR SLAB 4 IN (38 BY 18),
          STARTING AT (0,7,0) FACING (180) FLOOR SLAB 4 IN (30 BY 7),
          STARTING AT (30,7,0) FACING (180) FLOOR SLAB 4 IN (28 BY 12),
          STARTING AT (58,7,0) FACING (180) FLOOR SLAB 4 IN (62 BY 20),
          STARTING AT (120,7,0) FACING (180) FLOOR SLAB 4 IN (28 BY 12),
          STARTING AT (148,7,0) FACING (180) FLOOR SLAB 4 IN (30 BY 7);
      EXTERIOR WALLS:
          STARTING AT (58,-13,0) FACING (180) WALL (62 BY H1);
      WALLS TO UNCOOLED SPACE:
          STARTING AT (108,25,0) FACING (0) WALL2 (38 BY H1);
    CONTROLS = ADMIN COOL AND HEAT;
  PEOPLE = 1,ADMIN OFFICE OCCUPANCY;
  END ZONE;
  ZONE 5 "OFFICE B":
```

```
      ORIGIN:(161,0,0);
      NORTH AXIS=0;
      ROOF:
         STARTING AT (0,0,H1) FACING (180) ROOF (28 BY 28),
         STARTING AT (28,0,H1) FACING (180) ROOF (13 BY 19),
         STARTING AT (41,0,H1) FACING (180) ROOF (17 BY 10);
      FLOOR:
         STARTING AT (0,28,0) FACING (180) FLOOR39 (28 BY 28),
         STARTING AT (28,19,0) FACING (180) FLOOR39 (13 BY 19),
         STARTING AT (41,10,0) FACING (180) FLOOR39 (17 BY 10);
      EXTERIOR WALLS:
         STARTING AT (0,0,0) FACING (180) WALL (58 BY H1)
            WITH WINDOWS OF TYPE SINGLE PANE WITH BLINDS
            (5.33 BY H1) AT (1,67,0) AND (17,0) AND (48,0),
         STARTING AT (0,20,0) FACING (270) WALL (20 BY H1);
      PARTITIONS:
         STARTING AT (58,0,0) FACING (90) WALL1 (10 BY H1),
         STARTING AT (58,10,0) FACING (0) WALL1 (17 BY H1),
         STARTING AT (41,10,0) FACING (90) WALL1 (9 BY H1),
         STARTING AT (41,19,0) FACING (0) WALL1 (13 BY H1),
         STARTING AT (28,19,0) FACING (90) WALL1 (9 BY H1),
         STARTING AT (28,28,0) FACING (0) WALL1 (28 BY H1),
         STARTING AT (0,28,0) FACING (270) WALL (8 BY H1);
     LIGHTS = 6.26,ADMIN LIGHTS;
     CONTROLS = ADMIN COOL AND HEAT;
   PEOPLE = 4,ADMIN OFFICE OCCUPANCY;
   END ZONE;
   ZONE 6 "CONFERENCE B":
      ORIGIN: (202,10,0);
      NORTH AXIS = 0;
      ROOF:
         STARTING AT (0,0,H1) FACING (180) ROOF (17 BY 9),
         STARTING AT (-13,9,H1) FACING (180) ROOF (30 BY 14);
      FLOOR:
         STARTING AT (0,9,0) FACING (180) FLOOR39 (17 BY 9),
         STARTING AT (-13,23,0) FACING (180) FLOOR39 (30 BY 14);
      PARTITIONS:
         STARTING AT (0,0,0) FACING (180) WALL1 (17 BY H1),
         STARTING AT (17,0,0) FACING (90) WALL1 (23 BY H1),
         STARTING AT (17,23,0) FACING (0) WALL1 (30 BY H1),
         STARTING AT (-13,23,0) FACING (270) WALL1 (14 BY H1),
         STARTING AT (-13,9,0) FACING (180) WALL1 (13 BY H1),
         STARTING AT (0,9,0) FACING (270) WALL1 (9 BY H1);
       LIGHTS = 2.79,ADMIN LIGHTS;
       CONTROLS = ADMIN COOL AND HEAT;
    PEOPLE = 2,ADMIN OFFICE OCCUPANCY;
   END ZONE;
   ZONE 7 "CLASSROOM B":
      ORIGIN:(149,40,0);
      NORTH AXIS = 0;
      ROOF:
         STARTING AT (0,0,0) FACING (180) ROOF (70 BY 37);
      SLAB ON GRADE FLOOR:
         STARTING AT (0,37,0) FACING (180) FLOOR SLAB 4 IN (70 BY 37);
      PARTITIONS:
         STARTING AT (0,0,0) FACING (180) WALL2 (70 BY H1),
         STARTING AT (70,0,0) FACING (90) WALL1 (37 BY H1),
         STARTING AT (0,16,0) FACING (270) WALL2 (16 BY H1);
      EXTERIOR WALLS:
         STARTING AT (70,37,0) FACING (0) WALL (70 BY H1);
```

```
    WALLS TO UNCOOLED SPACES:
       STARTING AT (0,37,0) FACING (270) WALL2 (21 BY H1);
    LIGHTS = 13.54,ADMIN LIGHTS;
    CONTROLS = ADMIN COOL AND HEAT;
    PEOPLE = 25,ADMIN CLASSROOM OCCUPANCY;
END ZONE;
ZONE 102 "STORAGE B":
    ORIGIN: (219,0,0);
    NORTH AXIS=0;
    ROOF:
       STARTING AT (0,0,H1) FACING (180) ROOF (41 BY 77);
    SLAB ON GRADE FLOOR:
       STARTING AT (0,77,0) FACING (180) FLOOR SLAB 4 IN (41 BY 47);
    FLOOR:
       STARTING AT (0,30,0) FACING (180) FLOOR39 (41 BY 30);
    EXTERIOR WALLS:
       STARTING AT (0,0,0) FACING (180) WALL (41 BY H1),
       STARTING AT (41,0,0) FACING (90) WALL (77 BY H1),
       STARTING AT (41,77,0) FACING (0) WALL (41 BY H1);
    PARTITIONS:
       STARTING AT (0,77,0) FACING (270) WALL1 (77 BY H1);
    LIGHTS = 16.59, ADMIN LIGHTS;
    CONTROLS = ADMIN H ONLY;
    PEOPLE = 7,ADMIN OFFICE OCCUPANCY;
END ZONE;
 ZONE 1000 "BASEMENT"
     ORIGIN(77,0,0);
     NORTH AXIS = 0;
     BASEMENT WALLS
        STARTING AT (0,20,0) FACING (180) WALL2 (64 BY 8),
        STARTING AT (64,20,0) FACING (270) WALL2 (20 BY 8),
        STARTING AT (64,0,0) FACING (180) WALL2 (98 BY 8),
        STARTING AT (162,0,0) FACING (90) WALL2 (30 BY 8),
        STARTING AT (162,30,0) FACING  (0) WALL2 (162 BY 8),
        STARTING AT (0,30,0) FACING (270) WALL2 (10 BY 8);
       CEILING
         STARTING AT (0,20,8) FACING (180) CEILING39 (64 BY 10),
         STARTING AT (64,0,8) FACING (180) CEILING39 (98 BY 30);
       SLAB ON GRADE FLOOR
         STARTING AT (0,30,0) FACING (180) FLOOR SLAB 4 IN (64 BY 10),
         STARTING AT (64,30,0) FACING (180) FLOOR SLAB 4 IN (98 BY 30);
       CONTROLS = ADMIN H ONLY;
    PEOPLE = 3,ADMIN OFFICE OCCUPANCY;
       LIGHTS  = 6.26,ADMIN LIGHTS;
 END ZONE;
END BUILDING DESCRIPTION;
BEGIN FAN SYSTEM DESCRIPTION;
MULTIZONE SYSTEM 1 "MAIN" SERVING ZONE 1,2,3,4,5,6,7;
  FOR ZONE 1:
     SUPPLY AIR VOLUME = 3000;
END;
 FOR ZONE 2:
    SUPPLY AIR VOLUME = 1975;
 END;
 FOR ZONE 3:
    SUPPLY AIR VOLUME = 535;
 END;
 FOR ZONE 4:
    SUPPLY AIR VOLUME = 2405;
 END;
```

```
  FOR ZONE 5:
     SUPPLY AIR VOLUME = 2735;
  END;
  FOR ZONE 6:
     SUPPLY AIR VOLUME = 615;
  END;
  FOR ZONE 7:
     SUPPLY AIR VOLUME = 3000;
  END;
OTHER SYSTEM PARAMETERS:
   SUPPLY FAN EFFICIENCY = .6630;
   HOT DECK CONTROL = OUTSIDE AIR CONTROLLED;
   HOT DECK CONTROL SCHEDULE = (200 AT 5,80 AT 70);
   COLD DECK TEMPERATURE = 58;
   COLD DECK THROTTLING RANGE = 16;
   MIXED AIR CONTROL = ENTHALPY ECONOMY CYCLE;
   DESIRED MIXED AIR TEMPERATURE = 55;
END;
   EQUIPMENT SCHEDULES:
        HEATING COIL OPERATION = CONTINUOUS,78 MAXIMUM TEMPERATURE,
                                   -400 MINIMUM TEMPERATURE;
        COOLING COIL OPERATION = OFF,58 MINIMUM TEMPERATURE;
        MINIMUM VENTILATION SCHEDULE = OA VENT;
END;
END SYSTEM;
    UNIT VENTILATOR SYSTEM 101 "UNIT HEATER" SERVING ZONE 101;
      FOR ZONE 101
          SUPPLY AIR VOLUME = 500;
          REHEAT CAPACITY = 50000;
      END;
      EQUIPMENT SCHEDULES
      SYSTEM OPERATION = INTERMITTENT;
        HEATING COIL OPERATION = CONTINUOUS,78 MAXIMUM TEMPERATURE;
     END;
     OTHER SYSTEM PARAMETERS
        MIXED AIR CONTROL = FIXED AMOUNT;
        OUTSIDE AIR VOLUME = 0.;
        HOT DECK CONTROL = OUTSIDE AIR CONTROLLED;
        HOT DECK CONTROL SCHEDULE = (200 AT 5,80 AT 70);
     END;
END SYSTEM;
    UNIT VENTILATOR SYSTEM 102 "UNIT HEATER" SERVING ZONE 102;
      FOR ZONE 102
          SUPPLY AIR VOLUME = 500;
          REHEAT CAPACITY = 50000;
      END;
      EQUIPMENT SCHEDULES
    SYSTEM OPERATION = INTERMITTENT;
        HEATING COIL OPERATION = CONTINUOUS,78 MAXIMUM TEMPERATURE;
     END;
     OTHER SYSTEM PARAMETERS
        MIXED AIR CONTROL = FIXED AMOUNT;
        OUTSIDE AIR VOLUME = 0.;
        HOT DECK CONTROL = OUTSIDE AIR CONTROLLED;
        HOT DECK CONTROL SCHEDULE = (200 AT 5,80 AT 70);
     END;
END SYSTEM;
    SINGLE ZONE DRAW THRU SYSTEM 1000 "BASEMENT" SERVING ZONE 1000;
        FOR ZONE 1000
              SUPPLY AIR VOLUME = 11200;
```

```
          END;
        EQUIPMENT SCHEDULES
         SYSTEM OPERATION = INTERMITTENT,78 MAXIMUM TEMPERATURE,
                            -300 MINIMUM TEMPERATURE;
          HEATING COIL OPERATION = CONTINUOUS,78 MAXIMUM TEMPERATURE;
          COOLING COIL OPERATION = OFF;
          MINIMUM VENTILATION SCHEDULE = CONTINUOUS;
        END;
        OTHER SYSTEM PARAMETERS
        MIXED AIR CONTROL = FIXED AMOUNT;
        OUTSIDE AIR VOLUME = 11200;
SUPPLY FAN EFFICIENCY = .819;
        END;
END SYSTEM;
END FAN SYSTEM DESCRIPTION;
BEGIN CENTRAL PLANT DESCRIPTION;
END INPUT;
```

APPENDIX C:

STATISTICAL FORMULAS

$$\% \text{ Difference} = \frac{X-Y}{X}$$

$$\text{DIFFAVE} = \frac{\Sigma D}{N} \qquad \text{PERAVE} = \frac{\Sigma P}{N} \qquad \text{DABSAVE} = \frac{\Sigma \; D}{N}$$

$$\text{DIFFVAR} = \frac{N\Sigma D^2 - (\Sigma D)^2}{N\,(N-1)} \qquad \text{PERVAR} = \frac{N\Sigma P^2 - (\Sigma P)^2}{N\,(N-1)} \qquad \text{DABSVAR} = \frac{N\Sigma \; D^2 - (\Sigma \; D\;)^2}{N\,(N-1)}$$

DIFFSTD = DIFFVAR   PERSTD = PERVAR   DABBSTD = DABSVAR

where: X = measured
Y = predicted
D = X-Y
N = number of observations
P = D divided by X times 100

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